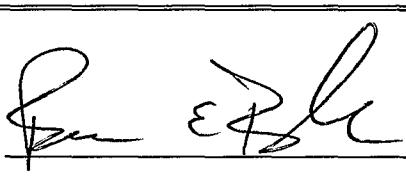Master of Military Studies

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TITLE:

**Smokeless Propellants as Vehicle Borne IED Main Charges:
An Initial Threat Assessment**

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF
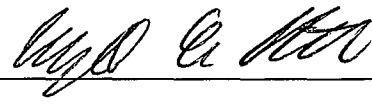MILITARY STUDIES

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Counter Terrorism Division

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Table of Contents

Executive Summary

Title: Smokeless Propellants as Vehicle Borne IED Main Charges: A Preliminary Threat Assessment

Author: Special Agent Steven L. Beggs, Bureau of Alcohol, Tobacco, Firearms and Explosives

Thesis: Significant and dangerous misconceptions exist concerning the potential use of smokeless propellants as the main explosive charge in a large vehicle borne improvised explosive devices (VBIED). The unrestricted availability of smokeless powder, coupled with a lack of awareness and appreciation for its destructive potential, constitute a considerable blind spot available for exploitation by violent extremist organizations and individuals.

Discussion: Conventional explosive materials remain the most probable terrorist attack scenario. Violent extremist groups continue to explore innovative attack options that take advantage of overlooked vulnerabilities inherent to the civilian sector. The Federal government defines smokeless propellants as low explosive materials designed to burn rather than detonate. This orthodox view of smokeless powder allows these propellants to remain virtually unregulated by the Federal government. The results of previous independent and government sponsored studies along with the results of preliminary live fire tests conducted in support of this report provide compelling evidence that smokeless powder is capable of unconfined detonation. The live fire tests were preformed to determine if unconfined propellants are capable of detonation when initiated with a commercial blasting cap. These tests, while greatly limited in scope, provide sufficient data to challenge orthodox notions of smokeless powder and emphasize the necessity for additional testing and research. The test results validate a fundamental, and often overlooked, distinction between the manner in which smokeless powder is designed to react (deflagrate) to a given stimuli (ammunition primer) and the manner in which it is capable of reacting (detonating) to unintended stimuli (detonator). This important distinction is commonly ignored or not understood and is the essence of this report.

Conclusion: Smokeless propellants represent some degree of threat to the security of the homeland. The government has thus far not assessed the extent of this threat. A valid threat assessment can only be accomplished through comprehensive testing and research. Political debate and expert consultation will not achieve a deep understanding of the potential threat. Smokeless powder may represent one piece of low hanging fruit waiting for some al-Qa'ida type to pick.

Introduction

We assess that al-Qa'ida's Homeland plotting is likely to continue to focus on prominent political, economic, and infrastructure targets designed to produce mass causalities, visually dramatic destruction, significant economic aftershocks, and/or fear among the population. We judge use of a conventional explosive to be the most probable al-Qa'ida attack scenario because the group is proficient with conventional small arms and improvised explosive devices (IEDs) and is innovative in creating capabilities and overcoming security obstacles. [1]

- Director of National Intelligence
Annual Threat Assessment
5 February 2008

Imagine for a moment that anyone in the United States with a computer and internet access could purchase unlimited quantities of explosive material and have them shipped directly to their home. Imagine that this hypothetical purchaser is not required to complete any official paperwork or undergo a background check to verify identity, citizenship, or criminal history. Take it another step and imagine that the explosives have equal or better performance characteristics (velocity of detonation) than the mixtures used in the Oklahoma City and World Trade Center bombings. The explosives require no alteration, mixing, additive, chemical modification or confinement – they are commercial off the shelf high explosives delivered directly to the purchaser's front door with literally no questions asked.

The reality of this scenario lies in the virtually unregulated commerce of smokeless powder – the explosive propellant used in small arms ammunition. Approximately 10 million pounds of smokeless powder is manufactured and sold in the United States each year. [2] Most of this powder is sold to licensed commercial ammunition manufacturers or to the military. The rest, approximately 3 million pounds annually, is marketed and sold to individual users in canisters as small as a ½ pound and up to 20 pounds. [3] Sportsman and target shooters who prefer to reload their own ammunition, primarily motivated by better performance and reduced costs,

drive the demand in the small container market. Federal restrictions on smokeless propellants are not prescribed to any degree past the manufacturing process permitting the retail powder market to remain virtually unregulated by the government.[4]

Criminals and terrorists in the United States account for a portion of the unregulated market as they occasionally use smokeless propellants to make improvised explosive devices (IED's).[5] The Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) reports that of the 4,740 bombings it investigated from 1998 to 2002, roughly 10 % of the incidents involved devices using smokeless powder as the main charge.[6] The ATF report indicates these devices were usually constructed using a rigid container, such as pipe, to confine the explosives, and hence frequently referred to as pipe bombs. Security and law enforcement professionals are keenly aware of the potential for smokeless powder to be used as explosive filler in a small IED based on official documents such as the ATF report and the abundance of bomb making information available on the Internet.

The intent of this report is not to provide evidence that smokeless powder is commonly used in pipe bombs, but to suggest that significant and dangerous misconceptions exist with regard to its potential use as the main explosive charge in a large vehicle borne improvised explosive device (VBIED). These misconceptions have led directly to a dangerous lack of awareness in law enforcement and security agencies, and even within the bomb disposal community. Lenient federal controls, inaccurate and incomplete government sponsored research, and flawed training curriculum continue to perpetuate these misconceptions. The unrestricted availability of smokeless powder, coupled with a lack of awareness and appreciation for its destructive potential, constitute a considerable blind spot available for exploitation by violent extremist organizations and individuals.

Methodology

This report examines the characteristics and properties of smokeless propellants and the federal explosives controls currently in place. The results of previous independent and government sponsored studies related to smokeless powder are provided along with the results of preliminary live fire tests conducted in support of this report. The live fire tests were preformed to determine if unconfined propellants are capable of detonation when initiated with a commercial blasting cap. These tests, while greatly limited in scope, provide sufficient data to challenge orthodox notions of smokeless powder and emphasize the necessity for additional testing and research. The test results validate a fundamental distinction between the manner in which smokeless powder is designed to react (deflagrate) to a given stimuli (ammunition primer) and the manner in which it is capable of reacting (detonating) to unintended stimuli (detonator). This important distinction is commonly ignored or not understood and is the essence of this report.

Essential Definitions

It is necessary to define the terminology relevant to a general discussion of explosives and more specifically smokeless powder. Low explosive, high explosive, deflagrate and detonate are the crucial terms that must be understood to facilitate an understanding of the essential points of this report. The definition of these terms along with definitions of other relevant explosives terminology can be can be found in Appendix A. The definitions are taken from a variety of sources and contain only the essential information necessary to define the terms. Although numerous references exist that provide definitions with some variation on those offered, the definitions provided are deemed commonly accepted and generally accurate descriptions of the terms. The definitions provided avoid, to the greatest extent possible, scientific and technical

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jargon and are most appropriate for the purposes of this report. These terms and definitions provide the basis for a partial understanding of how explosives are classified and in turn, to what degree they are regulated by the Federal government.

Smokeless Powder: Composition, Properties and Characteristics

Smokeless propellants are essentially mixtures of chemicals designed to burn under controlled conditions at the proper rate to propel a projectile from a gun.[7] They have been in existence for well over a century with French chemist Paul Vielle introducing the first smokeless powder in 1886. Vielle's mixture along with a smokeless propellant developed by Alfred Nobel in 1870 quickly replaced black powder as the preferred propellant charge used in small arms ammunition.[8] By the early 1900's most military and commercial small arms ammunition used smokeless powder as its main propellant charge. Refinements of Vielle and Noble's mixtures continued throughout the 20th century producing smokeless propellants for use in a wide variety of applications from small arms ammunition to large missiles and rockets.[9]

Smokeless powder is defined as a granular, free-flowing, solid propellant using nitrocellulose as an active ingredient. [10] Smokeless powders are most commonly grouped in three categories based on the chemical composition of their primary energetic ingredients: single-base, double-base and triple-base. [11] Single-base powders contain nitrocellulose, while double-base powders contain both nitrocellulose and nitroglycerin. Triple-base powders contain nitrocellulose, nitroglycerin, and nitroguanidine and are primarily used in highly specialized applications. Triple base powders are not generally available on the open market and are not relevant to this report. The ATF Forensic Science Laboratory estimates that there are currently 61 varieties of single-base and 76 varieties of double-base smokeless powders available on the

commercial US market.[12] These propellants are primarily used to manufacture small arms ammunition and are the focus of this report.

Single base powder uses nitrocellulose, also called guncotton, as its sole energetic material. Single base powder can be defined as nitrocellulose blended with various non-explosive additives that serve to reduce sensitivity, control performance and improve shelf life.[13] Single base smokeless powder has less chemical energy than double base and is generally formulated so that it burns more slowly.

Double base powder is a blend of nitrocellulose and nitroglycerin, along with stabilizers and other additives to control performance and increase shelf life. The amount of nitroglycerin present in various mixtures varies widely dependant on the desired performance parameters. Generally, nitroglycerin content ranges from just under 10% to 40% of the total composition of double base powders.[14] Double base powders contain more chemical energy than single-base powders are commonly ball, sphere or disc shaped.

While chemical composition is an important characteristic defining smokeless propellants and their performance, morphology plays an important supporting role. Morphology is the shape and size of the granules in a particular smokeless powder mixture and has profound effect on the burning rate and power generation of the powder.[15] Propellant powder burns from the surface in parallel layers. Therefore the energy liberated is a function of the surface area of reaction which is influenced to a great extent by particle size and shape. That is, for a given weight and composition of powder, particles of a larger surface area burn at a faster rate than do particles with a smaller surface area. Common particle shapes include thin circular flakes or wafers, spheres, discs, perforated discs, cylinders, perforated cylinders, and aggregates of these.[16] Some common types of smokeless powder morphologies are illustrated in Appendix B.

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Smokeless powder is defined as explosive propellants designed to burn at a controlled rate rather than detonate and therefore classified as a low explosive. However, the chemical composition of smokeless powder is significant and warrants close examination. Chemists define both nitrocellulose and nitroglycerin as nitrate esters, or compounds formed from the reaction between an alcohol and an acid. [17] These materials are highly energetic and are universally recognized as high explosives that can be detonated readily with all common detonators.[18] The velocity of detonation of pure nitrocellulose is 7300 meters per second (23,950 fps) and pure nitroglycerin is 7750 meters per second (25,426 fps). [19] While these numbers represent performance characteristics of pure forms of the materials in an ideal environment, it is significant that both single and double base powders derive all of their energetic capabilities from one or both of these materials.

Federal Explosives Laws and Regulations

Title XI of the Organized Crime Control Act of 1970 is the principal legislation establishing and defining explosives controls at the federal level. The legislation identifies criminal acts involving explosives and establishes regulatory controls over explosive materials. Title 27 of the Code of Federal Regulations (CFR) part 555 contains the regulations that implement Title XI. [20] Generally, the purpose of the legislation is to prevent the criminal or accidental misuse of explosives, ensure the safe and secure storage of explosives materials, and protect interstate and foreign commerce. The legislation provides penalties for violation of any part of the Act including both criminal and civil actions. These penalties range in severity from the revocation of licenses up to the imposition of the death penalty for capitol offenses involving the criminal use of explosives.

Licensing and permitting requirements are the central feature of the regulatory provisions. An explosives license is required for persons who engage in the business of importing, manufacturing, or dealing in explosive materials while a permit is required to acquire or transport explosives. The law requires any person or entity engaged in these activities, essentially anyone who uses explosives, to hold a federal explosives license or permit issued by the ATF. Persons applying for an explosives license or permit must submit a photograph and fingerprints to the ATF and undergo a background investigation. The law prohibits certain persons from obtaining a license or permit, such as convicted felons, fugitives, illegal aliens, mental defectives and those that have renounced their U.S. citizenship. There are currently 11,207 Federal explosives licenses and 11,433 permit holders in the United States. [21]

Record keeping and theft reporting are critical requirements of the federal licensing system. Accurate record keeping and prompt theft reporting are crucial first lines of defense in denying criminals access to explosives. The law requires license and permit holders to maintain timely and accurate acquisition and disposition records of explosive products and materials. This requirement, in theory, creates an accounting paper trail documenting the life cycle of explosive materials from manufacturer to dealer and ultimately to the end user. License and permit holders are required to promptly report to ATF any theft, loss or inventory shortage occurring within this life cycle. These requirements enable ATF and other law enforcement agencies to conduct timely and effective theft investigations, generate detailed investigative leads and provide accurate threat assessments related to stolen and missing explosives. The ATF's explosives tracing program that tracks stolen commercial explosives and explosives materials recovered by law enforcement relies almost entirely on the existence and accuracy of these records.

Explosives storage requirements are an additional component of the federal system prescribed

to enhance public safety and limit criminal access to explosives. The explosives storage requirements codified in 27 CFR part 555 mandate strict adherences to standardized safety and security protocols. These regulations define the manner in which explosive materials must be stored and delineate approved containers, locking mechanisms, separation distances, lighting and other requirements. All explosive materials are required to be stored in an approved container, commonly called a magazine. The regulation allows for storage in various types of approved magazines, depending upon the classification of the explosive material to be stored.

Each year ATF publishes the List of Explosive Materials which identifies the materials subject to regulation (Appendix C).[22] While not all inclusive, it is a comprehensive list of most all commercial and military explosives, including smokeless powder. The regulations divide the materials into three classes – high explosives, low explosives and blasting agents. The classifications defined below are taken directly from 27 CFR 555:

(a) High explosives. Explosive materials which can be caused to detonate by means of a blasting cap when unconfined, (for example, dynamite, flash powders, and bulk salutes).[23]

(b) Low explosives. Explosive materials which can be caused to deflagrate when confined (for example, black powder, safety fuses, igniters, igniter cords, fuse lighters, and "display fireworks" except for bulk salutes).[24]

(c) Blasting agents. Any material or mixture, consisting of fuel and oxidizer, that is intended for blasting and not otherwise defined as an explosive; if the finished product, as mixed for use or shipment, cannot be detonated by means of a number 8 test blasting cap when unconfined (for example, ammonium nitrate-fuel oil and certain water-gels).[25]

All explosives materials, regardless of classification, are subject to some degree of regulation. High explosives are subject to more stringent storage requirements than are blasting

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agents and low explosives. Additionally, materials classified as high explosives are subject to all the requirements of the federal regulations with very few exceptions. In contrast, the law grants numerous exemptions for materials classified as low explosives. Some of the low explosive materials that are exempted from most federal controls include consumer fireworks, model rocket motors containing low explosives, and commercial black powder in quantities of less than fifty pounds. [26] But perhaps the most wide-ranging exemption from regulation is the exclusion of small arms ammunition and components of small arms ammunition. Smokeless powder is an essential component of small arms ammunition and is therefore excluded from regulation. The exemption does not apply to manufacturers and importers of smokeless powder who must hold explosives licenses and comply with all the provisions of the legislation. All other restrictions related to the distribution, acquisition, storage, and record keeping of smokeless powder are exempted from regulation under 18 U.S.C. Chapter 40 and 27 CFR Part 555. [27]

The exemption allows for an entirely unrestricted retail smokeless powder market in the United States. This free market permits the distribution, sale, acquisition and storage of smokeless propellant regardless of quantity without any measure of federal oversight. Smokeless powder can be purchased at a variety of retail outlets including gun shops and hardware stores or the Internet. Electronic Internet transactions may be entirely devoid of personal interaction between buyer and seller. Some Internet dealers encourage bulk sales as a means for purchasers to reduce shipping costs (Appendix D). [28]

The fact that smokeless powder consistently ranks in the top five explosive materials used in criminal bombings each year in the United States is a predictable outcome of the exemption (Appendix E).[29] Under-reported smokeless powder theft is another likely result of the exemption. The exemption negates the requirement for smokeless powder dealers to hold

explosives licenses and in turn maintain records. It is assumed that the absence of inventory records adversely effects accurate theft reporting. Theft reports submitted to ATF from 1997 to 2005 provide some evidence for this assumption. Over this nine year span 27,409 pounds of high explosives (excluding detonators and detonating cord) and 42,438 pounds of blasting agents were reported stolen compared to a miniscule 22 pounds of smokeless powder reported stolen during the same period. [30] Perhaps the most debilitating effect of the exemption from a regulatory and security perspective is that it thwarts any means to track or monitor suspicious purchases such as usually large quantities or multiple successive purchases of smokeless powder.

Although the exemption permits an unrestricted smokeless powder market, with all its unintended consequences, it remains intact and ostensibly aligned with the congressional intent of the legislation. The purpose of the legislation, as put forth in Title XI, is to protect persons, property and commerce from the misuse or unsafe storage of explosives materials without imposing "any undue or unnecessary restrictions or burdens on law abiding citizens."[31] It can be argued that the criminal and regulatory provisions codified in the Organized Crime Control Act, augmented by the regulatory requirements proscribed in 27 CFR 555, are reasonable and comprehensive controls that fulfill the intent of Congress without imposing undue burdens on law abiding citizens. It may also be concluded that the smokeless powder exemption may very well be warranted based on the essential role it plays as a component of small arms ammunition, its classification as a low explosive and the fact that it has never been used in a large scale bombing. However, these conclusions should be made only after gaining an understanding of the capabilities of smokeless powder as an explosives charge and careful scrutiny of the conventional notions surrounding it.

Relevant Research and Associated Studies

In March of 1943 a chemistry professor at the Massachusetts Institute of Technology (MIT) named Tenney L. Davis published *The Chemistry of Powders and Explosives*. Davis wrote and published it as a textbook for chemistry and chemical engineering graduate students at MIT. The following excerpt is taken from page 4 of the book:

"...classes of explosives materials overlap somewhat, for the behavior of a number of them is determined by the nature of the stimuli to which there are subjected and by the manner in which they are used. Black powder has probably never been known, even in the hideous explosions which have occurred at black powder mills, to do anything but burn. Smokeless powder which is made from colloided nitrocellulose, especially if it exists in a state of fine subdivision, is a vigorous high explosive and may be detonated by means of a sufficiently powerful initiator."[32] Authors Josef Kohler and Rudolf Myer affirm Davis' conclusion in their book *Explosives*. They indicate, "The mode of reaction of an explosives material – deflagration or detonation –greatly depends on its mode of actuation." [33]

Studies related to the detonation properties of smokeless powder are surprisingly limited considering its wide use in both civilian and military applications. There is an abundance of reference material related to the study and characterization of smokeless powder as a propellant; however few credible references exist associated with the study of its detonation properties. Research associated with deflagration to detonation transitions (DDT) in confined smokeless propellants are the most relevant studies available, yet none precisely address instantaneous unconfined detonation.

A 2001 Japanese study conducted in response to an accidental explosion at a propellant manufacturing facility provides some relevant data (appendix F).[34] The researchers found very

few previous studies on the properties of smokeless powder and conclude, "...the study of smokeless powder has been somewhat suppressed in the past because these propellants are used almost exclusively for ammunition and as such are subject to security restrictions."[35]

The Japanese study examines five types of single base and four types of double base smokeless powders. The researchers performed a series of tests using two methods of initiation to detonate propellants confined in steel tubes. The test results document the occurrence of detonation in both the single and double base propellants. The study concludes smokeless powder is capable of detonation and that charge density is strongly related to the velocity of detonation regardless of the chemical composition (single or double-base) of the propellants. It is important to emphasize two crucial aspects of these tests. First, the test charges were encased in pressure resistant steel tubing and therefore confined. Secondly, the researchers utilized non standard initiation methods – fuse heads with black powder initiators and detonators boosted with high explosives (C-4).

The most valuable research available is a comprehensive 1988 Canadian study which examined the results of seven independent tests (Appendix G). The research documents test results compiled from separate studies by six European countries and the United States. The most relevant of these is a Finish study that performed cap sensitivity tests involving both single and double-based propellants. The test was performed by placing one kilogram of propellant into a plastic bag and suspending it one meter above the ground. A detonator was placed in the center of the bag and initiated. The test results indicated 16 of the 32 powders tested detonated when initiated with a number 8 commercial detonator. Overall the Canadian study makes several important conclusions:

- Most propellants will detonate when suitably initiated by an explosive source.[36]

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- Propellants have a critical diameter and an ideal diameter as in the case of all explosives materials.[37]

- The larger the quantity of smokeless propellants the greater the possibility for a high TNT equivalence." [38] (See appendix A: TNT equivalence).

Preliminary Test Results

The results of previous studies, while significant and highly relevant, fail to provide the essential data necessary for this report. The available research almost exclusively studies smokeless powder detonation in confined environments. Most explosives technicians know anecdotally from conducting post blast investigations involving smokeless powder filled pipe bombs that these propellants are capable of detonating. These same explosives technicians, along with policy makers at the highest levels of security and law enforcement agencies, do not widely recognize that smokeless propellants are capable of unconfined detonation. For this reason it was necessary to conduct a series of tests to determine if unconfined smokeless powder is capable of detonation when initiated with a commercial blasting cap. The extremely limited scope of the study warrants emphasis. A significant restrictive factor was the limited availability of smokeless propellants in extensive varieties and suitable quantities. The ATF Explosives Training Branch provided all the materials used in the tests from its surplus inventory. This limited the tests to a single type of double base smokeless propellant. The foremost limiting factor was simply that extensive and comprehensive scientific testing requires considerable time and funding along with the appropriate personnel, facilities, and instrumentation. It was not practical to attempt to overcome these limitations for the purpose of this report. The ATF Explosives Training Branch contribution of surplus explosives, technicians and access to its explosives demolition range at Fort AP Hill, Virginia mitigated these limiting factors sufficient

to conduct the tests. O.R.A. Incorporated contributed engineers and instrumentation and was equally vital to the performance of the tests. O.R.A. is a research and engineering firm specializing in energetic materials data collection.

The study consists of a series of tests shots using near identical charges and initiators. The test charge consists of a thin walled plastic bag filled with the sample propellant (Appendix H). Alliant Powder Bullseye brand double- base smokeless powder is the propellant test charge (Appendix I). The completed charge is placed atop a steel witness plate affixed with instrumentation to measure the velocity of detonation (Appendix J). An ICI aluminum shelled #8 electrical detonator is used to initiate each test shot. A photograph of a test charge prior to firing is shown in Appendix K. The test shots were fired sequentially and data was collected and documented. The O.R.A test report describes the data collection method and summarizes the tests results (Appendix L).

The test results document the occurrence of detonation in each of the four test shots. The highest velocity of detonation (VOD) was recorded at 25,641 fps and the lowest at 19,048 fps. The average VOD of all tests was measured at 21,282 fps. This is especially significant when compared to the known VOD of common high explosives and their TNT equivalency (Appendix M). [39] Trinitrotoluene, most commonly referred to as TNT, is the recognized standard by which explosives are compared – expressed as TNT relative equivalency (RE). The values shown in Appendix M demonstrate VOD is a significant factor in determining the RE of a given explosive. TNT detonates at velocity of 22,600 fps and represents the standard RE value of 1.00. RDX, the material used to make the military explosive C-4, detonates at 27,400 fps and is assigned an RE value of 1.60. Ammonium nitrate detonates at 8,900 fps and is assigned an RE value of 0.42. The test charge can be assigned an RE value of just under 1.00 using VOD as the lone

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determining factor. Exhibit N is a photograph depicting the steel witness plate after a test shot. The photograph provides additional evidence the test charge produces high detonation velocities.

The test results are even more significant when compared to the VOD estimates associated with the 1995 Oklahoma City bombing that killed 168 people and destroyed the Murray Federal Building. The FBI estimated the VOD of the ammonium nitrate and fuel oil (ANFO) main charge used that device to be around 13,000 fps.[40] The estimate has been questioned but most experts believe its velocity was somewhere between 7,000 and 15,600 fps.[41] The urea nitrate mixture used in the1993 World Trade Center bombing had an estimated VOD of between 11,000 and 15,500 fps. [42] The devastation resulting from the detonation of these devices provides some perspective related to the potential threat posed by smokeless powder.

Inaccurate and Incomplete Government Research

The bombings of the Murray Federal Building in Oklahoma City and the World Trade Center in New York prompted Congress to pass the Antiterrorism and Effective Death Penalty Act of 1996. The legislation consists of various measures intended to deter and punish acts of terrorism. The law also directs the Executive branch to perform a series of studies related to the prevention and investigation of bombings. The studies address a variety of subjects which include the appropriateness of current explosives controls and the feasibility of tagging explosive materials for detection and identification. ATF was tasked to conduct the studies on behalf the Executive branch but was directed by Congress not to include black or smokeless powder within the scope of its study. Congress directed the National Research Council (NRC) to conduct an independent study of black and smokeless powder. The NRC created the Committee on

Smokeless and Black Powder to perform the study. The Committee was directed to study two

basic subjects:

1. The feasibility of adding tracer elements to smokeless and black powder for the

    purpose of detection.[43]

2. The feasibility of adding tracer elements to smokeless and black powder for the

    purpose of identification.[44]

The committee completed its study in 1998 and published its findings in a report titled

Black and Smokeless Powder, Technologies for Finding Bombs and the Bomb Makers. The

report offers several recommendations and concludes that identification and detection taggants

should "not be implemented at the present time." [45] The committee made its recommendations

after conducting an exhaustive study of explosives taggants. The committee did not study the

explosive properties of black and smokeless powder, nor was it tasked to do so by Congress. The

committee's final report does however make important conclusions regarding the use of

propellant powders in improvised explosive devices. The report sites cost and containment as the

primary reasons propellant powders are not used in "car size bombs." [46] The committee indicates

that propellant powders generally sell for around $15 a pound compared to $1.50 a pound for

dynamite and $0.15 a pound for ANFO mixtures. The report goes on to state that very large

powder bombs are therefore not cost effective. The committee also concludes very broadly that,

"powders require containment to produce an explosion, and it is difficult to buy, construct, or

safely transport a container sufficiently robust to be used in a very large powder bomb." [47] The

committee did not perform any independent tests or research to support or validate these

conclusions. More fundamentally, the report failed to site references associated with these

conclusions leaving the reader to assume that they simply represent the combined experience of the committee.

Official reports such as this one continue to perpetuate a dangerous misconception. Broad assertion that propellant powders require confinement to produce an explosion is a gross oversimplification and is fundamentally inaccurate. The committee need only refer to common references and studies sited elsewhere in this report as evidence to the contrary. The committee's conclusions related to costs are naive at best. It is commonly known that black market prices on tightly controlled items like high explosives tend to be much higher than commercial prices. More importantly, the overall cost associated with organizing, planning and carrying out a large scale catastrophic IED attack may be of little significance to a well funded transnational terrorist cell. Regardless of costs, theft is always a reasonable option for criminals or terrorists. The prospect of stealing large quantities of smokeless powder may be an attractive alternative for savvy terrorists since no storage or security requirements in place. It is also likely that local police, as well as federal authorities, would under appreciate the significance of a large smokeless powder theft, especially compared to the theft of a large amount of high explosives. Based on current training curricula it is highly likely law enforcement officials at all levels of government would regard a large smokeless powder theft as a low priority.

Inaccurate and Misleading Training Curricula

"...devices using low explosives (smokeless powder) *tend to be small, the ½ to 2 lbs. range, because low explosives must be confined in a small hard container such as steel or PVC pipe. Large devices tend to be unconfined and must use a high explosive such as dynamite or ammonium nitrate and fuel oil..."* [48]

IED Awareness for First Responders Training Support Package

The above quote is taken directly from the text of an authoritative training publication produced and distributed in 2007 by the Department of Defense's Technical Support Working Group (TSWG). TSWG is a national interagency research and development program for combating terrorism and is widely recognized as an authority on Improvised Explosives Device technology. TSWG released the IED Awareness for First Responders Training Support Package for use by, "all Federal emergency and law enforcement officers, and all State and Local Fire, Law Enforcement, HAZMAT, Bomb Squad, and other emergency/public government services organizations, which may be involved with terrorist threats involving IEDs."[49] The training package represents the collaboration of virtually every federal security and law enforcement agency including the ATF, FBI and Department of Homeland Security as well as considerable contributions from the joint services explosives ordnance disposal (EOD) community. It is a reasonable assumption that the material presented in the TSWG IED training package is representative of training materials organic to each of the participating agencies. Based on this training curriculum it reasonable to assume that most law enforcement and security professionals, including the bomb disposal community, go about their vital duties of deterring, preventing and responding to acts of terror oblivious to the potential threat posed by the use of smokeless powder in a large scale IED attack.

Recommendations

The National Rifle Association (NRA) offers a simple, straight forward course of action for decision makers in the legislative and executive branches: Technical issues related to propellant powders must be removed from the political arena and into the domain of scientific research. [50] This statement represents a paraphrase of the NRA's 1998 recommendation for the National Academy of Science to study the issue of identification taggants and provides an

appropriate roadmap for policy makers. Premature political debate related to controls on smokeless powder and the resulting public debate is counterproductive and even dangerous. Effective and meaningful debate can only occur after comprehensive research establishes a base line that is founded in science instead of politics and opinion. It should be emphasized that tests conducted in support of this research, and certainly the test results, merit security classification at the appropriate level. The prospect that test results will generate unwanted interest from criminal and/or extremist elements is real and warrants tremendous caution.

The recommendations below represent a pragmatic and comprehensive approach to understand and evaluate the scope of threat. These recommendations do not call for testing all available powders on the market. The ATF Forensic Science Laboratory maintains a sample library of commercially available smokeless powder products. These products have been divided into a series of families based upon physical and chemical characterizations. It would be necessary to test only a limited number of commercial smokeless powder products representing each of these families. The study of the selected products should include the following tests:

Identification and Characterization of Powder:

This step will include obtaining any available information on the smokeless powder, as provided by the manufacturer, and conducting a limited chemical analysis of the powder to include the following:

a. Nitroglycerine content.

b. Nitrocellulose content.

c. Specific gravity.

d. Bulk density.

e. Grain dimensions.

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2. Unconfined Critical Diameter Test:

The smokeless powder will be loaded into a series of thin walled paper tubes (0.05 to 0.10 inch wall thickness), with inside diameters increasing in 0.5 inch increments (from 1 inch to 3 inches). The product will be loaded into the tubes with moderate tamping, and a bulk density of each charge will be measured. The charges will be primed with a standard test detonator (nominal #8 strength detonator). The detonation of the smokeless powder charge will be witnessed with VOD measurements.

3. Minimum Booster Test:

This test will be conducted on the powder loaded into a thin walled paper tube, with an inside diameter of at least 0.5 inches larger than that measured previously in the unconfined critical diameter test. The initial test will be conducted with a standard test detonator (nominal #8 strength detonator). In succeeding trials, the size of the booster will then be increased or decreased (fractional caps) as necessary. The detonation of the smokeless powder charge will be witnessed with VOD measurements.

4. Underwater Energy Test:

This test will be conducted on the powder loaded into 4 inch diameter PVC pipes (to provide water resistance), primed with a 50 gram cast Pentolite booster. The comparative shock energies and pressures will be measured and compared to those produced by an equivalent weight of cast TNT.

The study of smokeless powder has been almost wholly limited to its characteristics and performance as a propellant with little research dedicated to its explosives properties. Smokeless

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powder is one of the most ubiquitous explosive materials in American society and yet it may be the least understood. The government began studying fertilizer mixtures only after the horrific bombings in Oklahoma City and New York – now is the time to assess smokeless propellants.

Conclusion

Terrorists typically favor basic tactics, techniques and procedures (TTP), off-the shelf technology and readily available resources when planning and carrying out an attack. While simplistic in effort, these factors can be a lethal and destructive combination. Terrorists also continue to explore innovative attack options that take advantage of overlooked vulnerabilities inherent to the civilian sector."[51]
- Defense Intelligence Agency Report

The September 11, 2001 terrorist attacks prompted a seismic shift within the security agencies of the United States government. The tragic and unprecedented success of the attacks provoked a reengineering of the architecture of government and redirected the mission priorities of law enforcement and security agencies from response/mitigation/attribution to prevention. U.S. policy makers have spent the last eight years since the attacks implementing changes focused on preventing acts of terror on U.S. soil. The most visible evidence of these changes is codified in the USA Patriot Act of 2001, Homeland Security Act of 2002, the Intelligence Reform and Terrorism Prevention Act of 2004, and an array of Homeland Security Presidential Directives. These legislative actions and executives orders have realigned and redirected security efforts and made preventing terrorism the primary strategic objective of most every government agency from the Border Patrol to the Marine Corps. The prevention of catastrophic acts of terrorism is now front and center on the agenda of every law enforcement, security and intelligence agency within the Federal government.

The colossal shift in priorities and expanded government authority brings with them an expectation that the government is taking appropriate and prudent actions to prevent the next terrorist attack. Yet it remains possible for anyone in the United States with a computer and

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internet access to purchase an unlimited quantity of explosives and have them shipped directly to their home. Purchasers are not required to complete any official paperwork or undergo a background check to verify identity, citizenship or criminal history. It is likely that the explosives have equal or better performance characteristics than the mixtures used in the Oklahoma City and World Trade Center bombings.

Identifying, assessing and mitigating probable and even improbable threats are fundamental functions of the government. Smokeless propellants represent some degree of threat. The government, thus far, has not assessed the extent of that threat and it can only be determined through comprehensive testing and research. Political debate and expert consultation will not achieve a deep understanding of the potential threat. The appropriate research has never been conducted and is simply not available. The government has an opportunity to get ahead of the threat curve at a time when the enemy is "proficient with conventional small arms and improvised explosive devices and is innovative in creating capabilities."[52] Smokeless powder may very well represent one piece of low hanging fruit waiting for some al-Qa'ida type to pick. If this is true our enemies need not be innovative in creating capabilities at all – they just need a computer and a credit card.

Glossary of Terms

Confinement – may be defined as an inert material of some strength and having a given wall thickness, situated in the immediate vicinity of an explosives. Priming or heating the explosive materials produces different results, according to whether they are located in a stronger or weaker confinement. If confined by thick steel, almost any explosive will explode or detonate on being heated; on the other hand they burn on contact with an open flame if unconfined, except for initiating explosives. The destructive effect of an explosion becomes stronger if the explosive is confined in an enclosure. [53]

Deflagration – one of the two basic mechanisms or types of chemical explosion, the other being detonation. Generally, the term deflagration implies the burning of a substance with self-contained oxygen so that the reaction zone advances into the un-reacted material at less than sonic velocity [< 2,000 meters (6,500 feet) per second]. Unlike detonation, the deflagration rate of an explosive consists of the chemical burning of the material wherein its propagation rates are dependent on chemical kinetics. In this case, heat is transferred from the reacted to the un-reacted material by conduction and convection.[54] The propagation of an explosion reaction through a deflagrating explosive is therefore based on thermal reactions. The explosive material surrounding the initial exploding site is warmed above its decomposition temperature causing it to explode. Explosives such as propellants exhibit this type of explosion mechanism. Transfer of energy by thermal means through a temperature difference is a relatively slow process and depends very much on external conditions such as ambient pressure. The speed of the explosion is always subsonic: that is, it is always less than the speed of sound.[55]

Critical Diameter – The minimum diameter for propagation of a detonation wave at a stable velocity. It is affected by conditions of confinement, temperature, and pressure on the explosives. It is strongly texture dependent, and is larger in cast than in pressed charges.[56]

Deflagration to Detonation Transition (DDT) – burning to detonation can occur when an explosive substance is confined in a rigid container or self confined by volume and ignited. The gas generated from the chemical decomposition if the explosive material becomes trapped, resulting in an increase in pressure at the burning surface; this in turn raises the linear burning rate. In detonating explosives the linear burning rate is raised so high by pressure pulses generated at the burning surface that it exceeds the velocity of sound, resulting in detonation.[57]

Density – the weight per unit of volume of explosive, expressed as cartridge count or grams per cubic centimeter or pounds per cubic foot. Density is an important characteristic of an explosive. Raising the density (i.e. by pressing or casting) improves brisance and detonating velocity.[58]

Detonation – an explosion phenomenon of almost instantaneous decomposition. Although initiation to detonation does not take place instantaneously, the delay is negligible, being in microseconds.[59] It is an exothermic chemical reaction that propagates through the reaction zone toward the un-reacted material at a supersonic velocity forming a propagating shock wave. Thus, a detonation may be defined as an explosion process of

supersonic velocity involving a sustained shock wave. Normally a detonation is brought about by a shock wave traveling at supersonic velocity through the material.[60] Detonation can be achieved either by burning to detonation or by an initial shock.[61]

High Explosive – Explosive substances which on initiation decompose via the passage of a shockwave rather than a thermal mechanism.[62] Literally a high explosive means any explosive that detonates. In practice, the term is usually confined to explosives that decompose by detonation. Hence, high explosives are also called detonating explosives. A high explosive is characterized by a very high (supersonic) rate of reaction, high pressure development, and the presence of a detonation wave in the explosive. The rate of detonation of high explosives range from 1,000 to 8,500 meters (3300 to 28,000 feet) per second. [63]

Low explosive – an explosive which undergoes a relatively slow chemical transformation, thereby producing a deflagration or an explosion, i.e. the speed of the reaction is less than the speed of sound. No shock wave is generated and the reaction is propagated by very rapid burning. That is to say, a low explosive is characterized by deflagration or a low rate of reaction and the development of low pressure. In order for a low explosive to explode, it must be contained in a strong enclosure. Low explosives burn at a steady speed and are referred to as burning mixtures. Examples of low explosives are gunpowder, propellants, etc.[64]

Morphology – particle geometry or shape and size of granules. Common particle shapes of smokeless propellants include balls, discs, perforated discs, tubes, perforated tubes, and aggregates. A few common types of smokeless powder morphologies can be seen in Figure 1 below.[65]
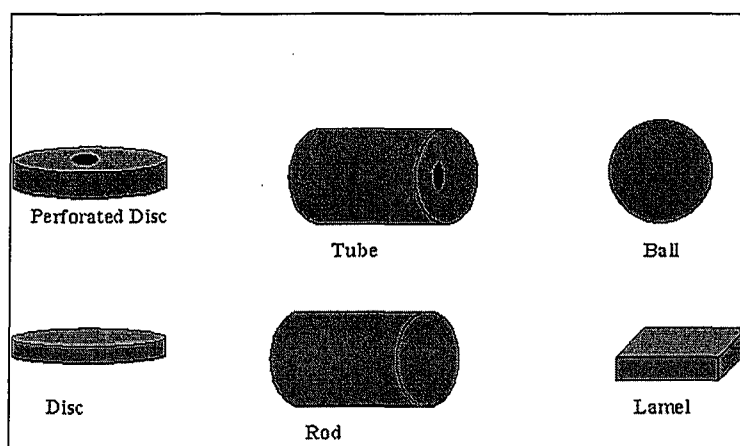
Number 8 Test Detonator – a detonator, also called a blasting cap, containing 2 grams of a mixture of 80 percent mercury fulminate and 20 percent potassium chlorate, or a detonator of equivalent strength. An equivalent strength detonator comprises 0.40 – 0.45 grams of PETN base charge pressed in an aluminum shell with bottom thickness not to exceed to 0.30 of an inch, to a specific gravity of not less than 1.4 g/cc., and primed with standard weights of primer depending on the manufacturer. [66]

TNT Equivalent – term used as a measure of the blast effects from the explosion of a given quantity of material expressed in terms of the weight of TNT that would produce the same blast effects when detonated. [67]

Velocity of Detonation – The rate at which the detonation wave travels through a high explosive. It may be measure confined or unconfined. The unit of the rate of reaction is meters/seconds or feet/second. Velocity of detonation of high explosive shock wave usually varies from 2,000 meters/second (6500 feet/second) to 8,000 meters/second (26,000 feet/second).[68]

Web Size – The distance of travel of a burning surface in a propellant grain to give complete combustion.[69]
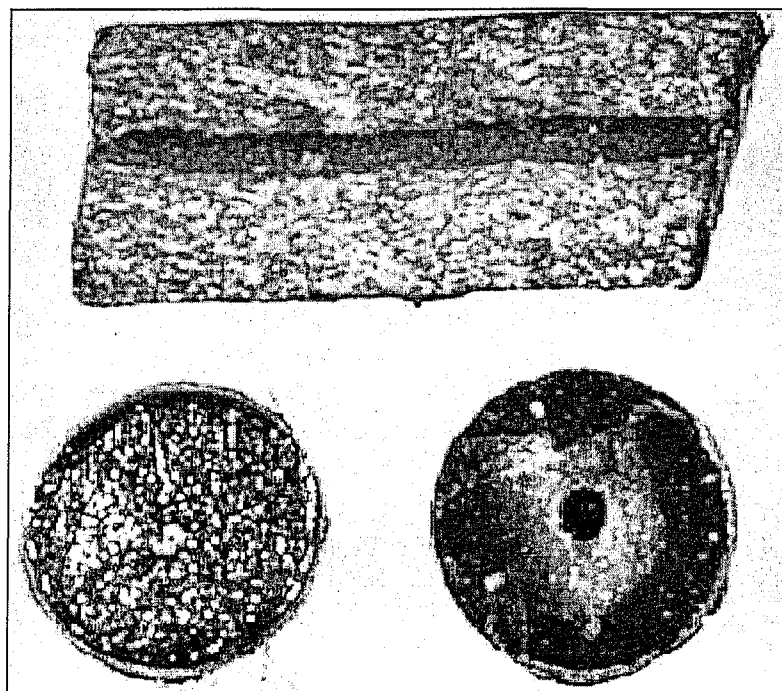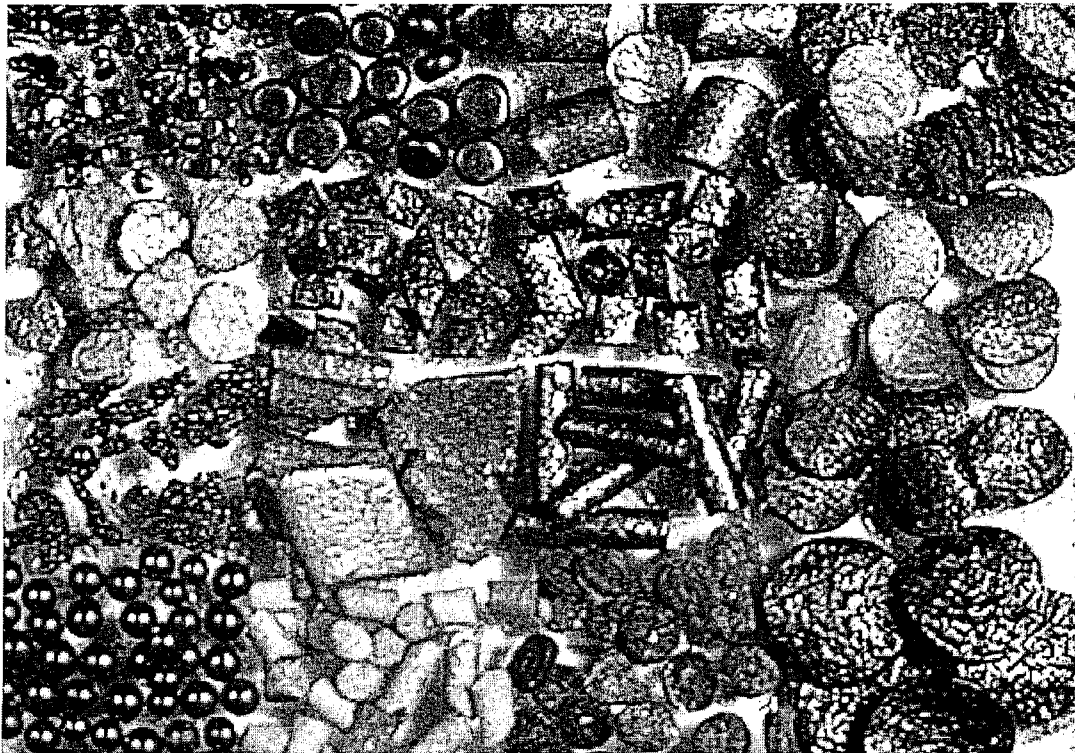
Appendix B
Bureau of Alcohol, Tobacco, Firearms and Explosives

List of Explosive Materials

Pursuant to the provisions of section 841(d) of title 18, U.S.C., and 27 CFR 555.23, the Director, Bureau of Alcohol, Tobacco, Firearms and Explosives, must revise and publish in the Federal Register at least annually a list of explosives determined to be within the coverage of 18 U.S.C. Chapter 40, Importation, Manufacture, Distribution and Storage of Explosive Materials. This chapter covers not only explosives, but also blasting agents and detonators, all of which are defined as explosive materials in section 841(c) of title 18, U.S.C. Accordingly, the following is the current List of Explosive Materials subject to regulation under 18 U.S.C. Chapter 40. Materials constituting blasting agents are marked by an asterisk. While the list is comprehensive, it is not all-inclusive. The fact that an explosive material may not be on the list does not mean that it is not within the coverage definitions in section 841 of title 18, U.S.C. Explosive materials are listed alphabetically by their common names, followed by chemical names and synonyms in brackets. This revised list is effective as of September 18, 2006.

List of Explosive Materials

A
Acetylides of heavy metals.
Aluminum containing polymeric propellant.
Aluminum ophorite explosive.
Amatex.
Amatol.
Ammonal.
Ammonium nitrate explosive mixtures (cap sensitive).
*Ammonium nitrate explosive mixtures (non-cap sensitive).
Ammonium perchlorate having particle size less than 15 microns.
Ammonium perchlorate composite propellant.
Ammonium perchlorate explosive mixtures.
Ammonium picrate [picrate of ammonia, Explosive D].
Ammonium salt lattice with isomorphously substituted inorganic salts.
*ANFO [ammonium nitrate-fuel oil].
Aromatic nitro-compound explosive mixtures.
Azide explosives.

B
Baranol.
Baratol.
BEAF [1,2-bis (2, 2-difluoro-2-nitroacetoxyethane)].
Black powder.
Black powder based explosive mixtures.
*Blasting agents, nitro-carbo-nitrates, including non-cap sensitive slurry and water gel explosives.
Blasting caps.
Blasting gelatin.
Blasting powder.
BTNEC [bis (trinitroethyl) carbonate].
BTNEN [bis (trinitroethyl) nitramine].
BTTN [1,2,4 butanetriol trinitrate].
Bulk salutes.

Butyl tetryl.

C
Calcium nitrate explosive mixture.
Cellulose hexanitrate explosive mixture.
Chlorate explosive mixtures.
Composition A and variations.
Composition B and variations.
Composition C and variations.
Copper acetylide.
Cyanuric triazide.
Cyclonite [RDX].
Cyclotetramethylenetetranitramine [HMX].
Cyclotol.
Cyclotrimethylenetrinitramine [RDX].

D
DATB [diaminotrinitrobenzene].
DDNP [diazodinitrophenol].
DEGDN [diethyleneglycol dinitrate].
Detonating cord.
Detonators.
Dimethylol dimethyl methane dinitrate composition.
Dinitroethyleneurea.
Dinitroglycerine [glycerol dinitrate].
Dinitrophenol.
Dinitrophenolates.
Dinitrophenyl hydrazine.
Dinitroresorcinol.
Dinitrotoluene-sodium nitrate explosive mixtures.
DIPAM [dipicramide; diaminohexanitrobiphenyl].
Dipicryl sulfone.
Dipicrylamine.
Display fireworks.
DNPA [2,2-dinitropropyl acrylate].
DNPD [dinitropentano nitrile].
Dynamite.

E
EDDN [ethylene diamine dinitrate].
EDNA [ethylenedinitramine].
Ednatol.
EDNP [ethyl 4,4-dinitropentanoate].
EGDN [ethylene glycol dinitrate].
Erythritol tetranitrate explosives.
Esters of nitro-substituted alcohols.
Ethyl-tetryl.
Explosive conitrates.
Explosive gelatins.
Explosive liquids.
Explosive mixtures containing oxygen-releasing inorganic salts and hydrocarbons.
Explosive mixtures containing oxygen-releasing inorganic salts and nitro bodies.
Explosive mixtures containing oxygen-releasing inorganic salts and water insoluble fuels.
Explosive mixtures containing oxygen-releasing inorganic salts and water soluble fuels.
Explosive mixtures containing sensitized nitromethane.

Explosive mixtures containing tetranitromethane (nitroform).
Explosive nitro compounds of aromatic hydrocarbons.
Explosive organic nitrate mixtures.
Explosive powders.

F
Flash powder.
Fulminate of mercury.
Fulminate of silver.
Fulminating gold.
Fulminating mercury.
Fulminating platinum.
Fulminating silver.

G
Gelatinized nitrocellulose.
Gem-dinitro aliphatic explosive mixtures.
Guanyl nitrosamino guanyl tetrazene.
Guanyl nitrosamino guanylidene hydrazine.
Guncotton.

H
Heavy metal azides.
Hexanite.
Hexanitrodiphenylamine.
Hexanitrostilbene.
Hexogen [RDX].
Hexogene or octogene and a nitrated Nmethylaniline.
Hexolites.
HMTD
[hexamethylenetriperoxidediamine].
HMX [cyclo-1,3,5,7-tetramethylene 2,4,6,8-tetranitramine;
Octogen].
Hydrazinium nitrate/hydrazine/aluminum explosive system.
Hydrazoic acid.

I
Igniter cord.
Igniters.
Initiating tube systems.

K
KDNBF [potassium dinitrobenzofuroxane].

L
Lead azide.
Lead mannite.
Lead mononitroresorcinate.
Lead picrate.
Lead salts, explosive.
Lead styphnate [styphnate of lead, lead trinitroresorcinate].
Liquid nitrated polyol and trimethylolethane.
Liquid oxygen explosives.

M
Magnesium ophorite explosives.
Mannitol hexanitrate.
MDNP [methyl 4,4-dinitropentanoate].
MEAN [monoethanolamine nitrate].
Mercuric fulminate.

Mercury oxalate.
Mercury tartrate.
Metriol trinitrate.
Minol-2 [40% TNT, 40% ammonium nitrate, 20% aluminum].
MMAN [monomethylamine nitrate]; methylamine nitrate.
Mononitrotoluene-nitroglycerin mixture.
Monopropellants.

N
NIBTN [nitroisobutametriol trinitrate].
Nitrate explosive mixtures.
Nitrate sensitized with gelled nitroparaffin.
Nitrated carbohydrate explosive.
Nitrated glucoside explosive.
Nitrated polyhydric alcohol explosives.
Nitric acid and a nitro aromatic compound explosive.
Nitric acid and carboxylic fuel explosive.
Nitric acid explosive mixtures.
Nitro aromatic explosive mixtures.
Nitro compounds of furane explosive mixtures.
Nitrocellulose explosive.
Nitroderivative of urea explosive mixture.
Nitrogelatin explosive.
Nitrogen trichloride.
Nitrogen tri-iodide.
Nitroglycerine [NG, RNG, nitro, glyceryl trinitrate,
trinitroglycerine].
Nitroglycide.
Nitroglycol [ethylene glycol dinitrate, EGDN].
Nitroguanidine explosives.
Nitronium perchlorate propellant mixtures.
Nitroparaffins Explosive Grade and ammonium nitrate mixtures.
Nitrostarch.
Nitro-substituted carboxylic acids.
Nitrourea.

O
Octogen [HMX].
Octol [75 percent HMX, 25 percent TNT].
Organic amine nitrates.
Organic nitramines.

P
PBX [plastic bonded explosives].
Pellet powder.
Penthrinite composition.
Pentolite.
Perchlorate explosive mixtures.
Peroxide based explosive mixtures.
PETN [nitropentaerythrite, pentaerythrite tetranitrate,
pentaerythritol tetranitrate].
Picramic acid and its salts.
Picramide.
Picrate explosives.
Picrate of potassium explosive mixtures.
Picratol.
Picric acid (manufactured as an explosive).
Picryl chloride.

Picryl fluoride.
PLX [95% nitromethane, 5% ethylenediamine].
Polynitro aliphatic compounds.
Polyolpolynitrate-nitrocellulose explosive gels.
Potassium chlorate and lead sulfocyanate explosive.
Potassium nitrate explosive mixtures.
Potassium nitroaminotetrazole.
Pyrotechnic compositions.
PYX [2,6-bis(picrylamino)] 3,5-dinitropyridine.

R
RDX [cyclonite, hexogen, T4, cyclo-1,3,5,-trimethylene-2,4,6,-trinitramine; hexahydro-1,3,5-trinitro-S-triazine].

S
Safety fuse.
Salts of organic amino sulfonic acid explosive mixture.
Salutes (bulk).
Silver acetylide.
Silver azide.
Silver fulminate.
Silver oxalate explosive mixtures.
Silver styphnate.
Silver tartrate explosive mixtures.
Silver tetrazene.
Slurried explosive mixtures of water, inorganic oxidizing salt, gelling agent, fuel, and sensitizer (cap sensitive).
Smokeless powder.
Sodatol.
Sodium amatol.
Sodium azide explosive mixture.
Sodium dinitro-ortho-cresolate.
Sodium nitrate explosive mixtures.
Sodium nitrate-potassium nitrate explosive mixture.
Sodium picramate.
Special fireworks.
Squibs.
Styphnic acid explosives.

T
Tacot [tetranitro-2,3,5,6-dibenzo-1,3a,4,6a tetrazapentalene].
TATB [triaminotrinitrobenzene].
TATP [triacetonetriperoxide].
TEGDN [triethylene glycol dinitrate].
Tetranitrocarbazole.
Tetrazene [tetracene, tetrazine, 1 (5-tetrazolyl)-4-guanyl tetrazene hydrate].
Tetrazole explosives.
Tetryl [2,4,6 tetranitro-N-methylaniline].
Tetrytol.
Thickened inorganic oxidizer salt slurried explosive mixture.
TMETN [trimethylolethane trinitrate].
TNEF [trinitroethyl formal].
TNEOC [trinitroethylorthocarbonate].
TNEOF [trinitroethylorthoformate].
TNT [trinitrotoluene, trotyl, trilite, triton].
Torpex.
Tridite.

Trimethylol ethyl methane trinitrate composition.
Trimethylolthane trinitratenitrocellulose.
Trimonite.
Trinitroanisole.
Trinitrobenzene.
Trinitrobenzoic acid.
Trinitrocresol.
Trinitro-meta-cresol.
Trinitronaphthalene.
Trinitrophenetol.
Trinitrophloroglucinol.
Trinitroresorcinol.
Tritonal.

U
Urea nitrate.

W
Water-bearing explosives having salts of oxidizing acids and nitrogen bases, sulfates, or sulfamates (cap sensitive).
Water-in-oil emulsion explosive compositions.

X
Xanthamonas hydrophilic colloid explosive mixture.

Approved: September 18, 2006.
Michael J. Sullivan, Acting Director.

A favorite of handloaders since 1946, Hodgdon powders have long delivered superior match-grade accuracy.

ATTENTION: Residents of DC, MA and NY please check your local laws for restrictions before ordering any gun-powder products, primers or percussion caps.

WARNING: Primers, Smokeless Powders, Pyrodex®, Triple Se7en®, Black Mag 3® and American Pioneer™ may only be purchased by adults. Check your local and state laws for the legality of ordering and possessing these products. Primers and Smokeless Powders are restricted in Washington D.C. For safety reasons, we do not accept returns on these products. Due to special shipping requirements for these products, UPS assesses an additional $20 Hazardous Material Handling charge to deliver EACH package of these products. Buying in bulk can save you money since you will be charged the same $20 fee for 1 lb. of powder as you will be charged for a larger quantity.

Appendix D

http://www.cabelas.com/link-12/product/0009716210742a.shtml

Department of the Justice
Bureau of Alcohol, Tobacco, Firearms, & Explosives
Arson and Explosives Programs Division
Arson and Explosives National Repository Branch

1-800-461-8841
AENRB@ATF.GOV
Acting Branch Chief Marion Burrows

March 7, 2003   Prepared By: R. S. Simpson

Explosive Filler Materials
Found in
Bombings
(1998-2002)

LAW ENFORCEMENT SENSITIVE

EXPLOSIVES RELATED FILLER MATERIAL[1]

The Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) is charged with maintaining a national database on arson and explosive related incidents. The information contained herein was compiled from information within the Arson and Explosives Incidents System (AEXIS) database, maintained by the Arson & Explosives National Repository Branch.[2]

A query of filler materials use in bombing incidents[3] in the AEXIS database for, between the years of 1998 and 2002, identified 4,740 records. "FLAMMABLE LIQUID" and "POTASSIUM CHLORATE/CHEMICALS/SOLIDOX/ETC" had the leading percentages with twenty-seven and twenty-six percent, respectively. In the sub-category of "FLAMMABLE LIQUID" improvised incendiary devices commonly known as "Molotov Cocktails" account for the vast majority of the incidents. Over-pressure devices, commonly known as "MacGyver Bombs"; Dry-Ice Bombs"; and "Drano Bombs", account for a significant amount of the "POTASSIUM CHLORATE/CHEMICALS/SOLIDOX/ETC" sub-category. However, this does not preclude other improvised explosive mixture found in this sub-category.

Filler Charge	Number
AMMONIUM NITRATE/PRILLS	6
ANFO	24
BLACK POWDER	574
BLASTING AGENT	3
BOOSTER	6
C4	2
DYNAMITE	29
DYNAMITE BINARY	7
FLAMMABLE GAS	140
FLAMMABLE LIQUID	1271
FLAMMABLE SOLID	12
MATCH HEADS	75
NITROGLYCERINE	2
OTHER	315
PETN	5
PHOTO FLASH POWDER	564
POTASSIUM CHLORATE/CHEMICALS/SOLIDOX/ETC.	1246
SMOKELESS POWDER	454
TNT	5

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[1] Filler materials are those compounds intended to cause an explosion and/or deflagration, found in explosives, improvised explosive devices (IED), and improvised incendiary devices (IID).

[2] The ATF Arson & Explosives National Repository Branch (AENRB) maintains AEXIS. ATF initially began collection bomb -related data on April 1, 1975, storing that data in the Explosives Incidents System (EXIS). AEXIS is an updated database management system which, using current technology, combines historical data from the older EXIS. Consequently, there have been over 100,000 arson and explosives related records entered in the database.

[3] Bombing incidents can be an actual or attempted bombing, or an actual or attempted incendiary bombing.

OTHER
7%

NITROGLYCERINE
0%

MATCH HEADS
2%

FLAMMABLE SOLID
0%

FLAMMABLE LIQUID
27%

FLAMMABLE GAS
3%

DYNAMITE BINARY
0%

DYNAMITE
1%

C4
0%

BLASTING AGENT
0%

BOOSTER
0%

PETN
0%

PHOTO FLASH POWDER
12%

POTASSIUM
CHLORATE/CHEMICALS/SOL
IDOX/ETC.
26%

SMOKELESS POWDER
10%

AMMONIUM
NITRATE/PRILLS
0%

TNT
0%

ANFO
1%

BLACK POWDER
12%

ATF
Arson and Explosives National Repository
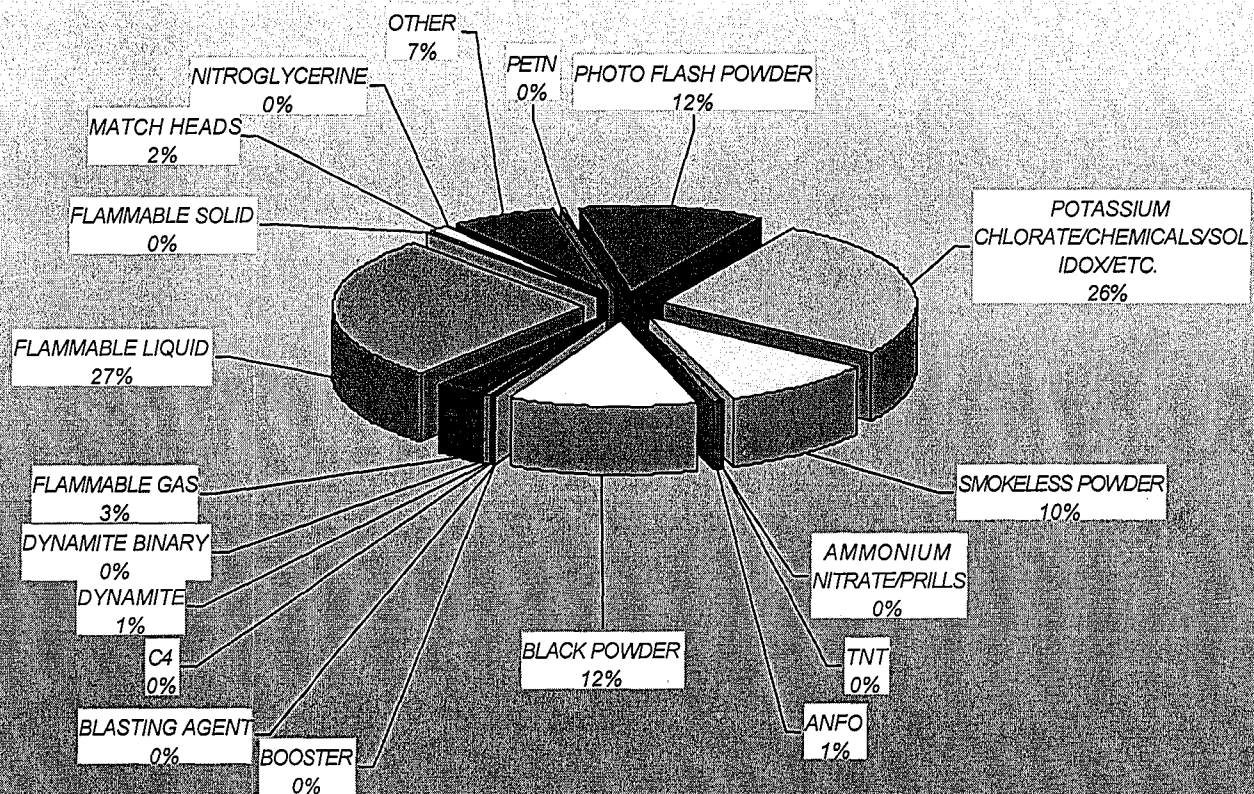
Detonation velocities of single and double base propellants

Ken Okada[*], Tomoharu Matsumura[*], Yoshio Nakayama[*], Hisashi Iguchi[**]
Masamichi Ishiguchi[**], Toshihiko Uchikawa[**], Tetsuya Sawada[**],
Kazushige Kato[**], Akihiko Yamamoto[**], and Masatake Yoshida[*]

The detonation velocity of single base and double base propellants is investigated using two types of ignititor; an exploding bridgewire detonator with C4, and a fuse head with black powder. In the former case, steady-state detonation is achieved and measured, while in the latter case, deflagration-to-detonation transition (DDT) behavior is observed. The detonation velocities of three single base and five double-base propellants are measured, and density correction is applied using KHT and CHEETAH computational code to account for the difficulty in ensuring a constant charge density in the experiments. The diameter effect for single and double base propellants is also determined with respect to the detonation velocity. The calculated detonation velocities at infinite charge diameter are 3624 m·s^{-1} for single base (35I) propellants and 4134 m·s^{-} for double-base (SS) propellants, and the calculated results are shown to be highly consistent with the experimental findings.

KEYWORDS: single base propellants, double base propellants, detonation velocity, smokeless powder, diameter effect

1. Introduction

On August 1, 2000, an explosion occurred at the Taketoyo plant of the NOF Corporation in Aichi prefecture, Japan. The explosion was attributed to 7.7 t of smokeless powder that had been stored at the facility, and resulted in injuries to 79 people and damage to 888 houses in the area[1]. Based on the report, which detailed the creation of a large crater in the concrete storage facility, the explosives are considered to have detonated rather than

undergoing combustion and deflagration. The sequence of event leading to the accident, as indicated by an interim report presented on October 23, 2000 by the investigation committee, is as follows. The smokeless powder, which ages rapidly, was stored in a temporary storage facility for a long period. On the day of the accident, it is thought that the temperature inside the storage facility rose due to solar radiation, which triggered spontaneous ignition and the subsequent explosion.

The present authors have begun to examine the triggers of this accident, starting with the detonation properties in terms of deflagration-to-detonation transition (DDT) behavior and detonation velocity (DV). In this report, we present the results of an investigation into these properties.

Smokeless powder is a ballistic propellant that can be categorized into three forms; single base propellants (SBs), double base propellants (DBs) and triple-base propellants (TBs). The facility in which the accident occurred was used temporarily to store SB and DB, with only a small amount of

TB. In this study, we are therefore concerned primarily with SB and DB. As these smokeless powders do not generally detonate, we will attempt to determine whether these propellants did in fact detonate, and measure the DV of these propellants. Our detailed investigation of the DDT of various smokeless powders will be presented in another paper.

There has been quite a lot of research recently on stabilizing agents for SB and DB propellants[2,3]. Many solid propellants, although much less sensitive to initiation by shock or other stimuli compared to most high propellants, are detonatable in charge sizes small enough to make storage and handling of such compositions extremely hazardous. There has been some research relating to the DV of SB and DB propellants, and it has been reported that the DV of smokeless powders is not related to the charge diameter, although the accuracy of these measurement is in doubt[4]. In related research, the failure diameter and DV were measured as functions of diameter for several plastisol-nitrocellulose composite propellants, and for ammonium perchlorate and C4 for comparison[5]. It is clear from these studies that the DV is the most important detonation parameter. It is notable that there are very few studies on the properties of smokeless powders. Research related to smokeless powders has been somewhat suppressed in the past because these propellants are used almost exclusively for ammunition and as such are subject to security restrictions.

In this study, the properties of commercial SB and DB propellants are investigated with respect to the variation in steady-state DV with charge radius in a cylindrical geometry (the "diameter effect"). There is a considerable amount of previous research on the diameter effect, specifically relating to composition B[6], high-density heterogeneous explosives[7], ammonium perchlorate[8], and H_2O_2/H_2O mixtures[9].

2. Experimental

Photographs of 35I (SB propellant) and SS (DB propellant) are shown in Fig. 1. 35I is cylindrical, while SS is disc shaped. The shape and internal pore size of smokeless powder differs according to
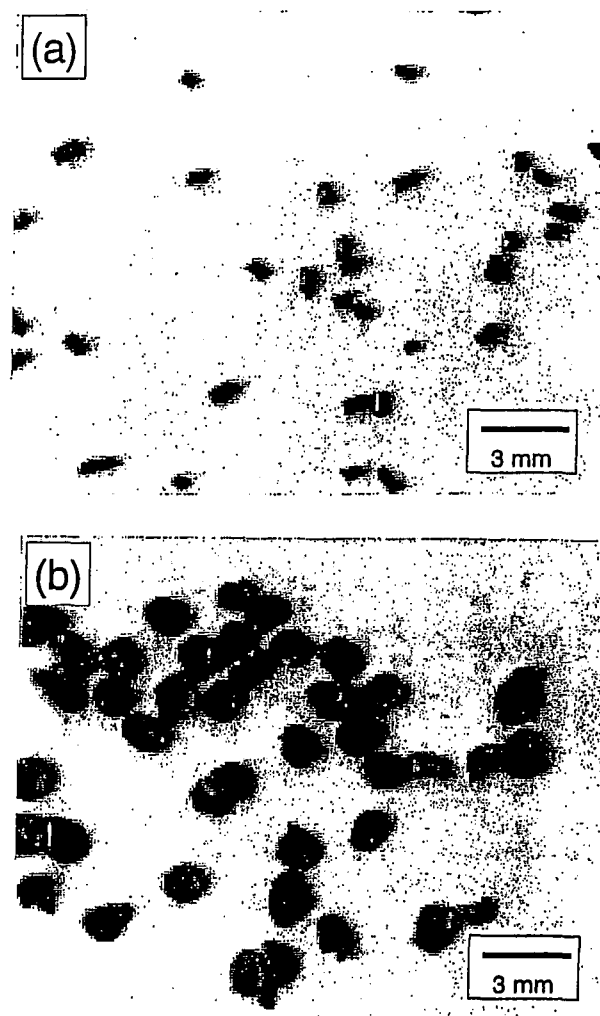
Fig.1 Photographs of (a) single base and (b) double base propellants

the application in order to achieve a desired burning velocity and ignitability. In this study we examine 5 types of SB propellant and 4 types of DB propellant with respect to the density of propellants and the diameter of the experimental assembly, without paying specific attention to the shape and internal pore size of the materials themselves. Figures 2(a) and (b) show the two experimental assemblies. Type (b) is the BAM standard.

Propellants were encased in plain carbon steel tubing as used in the United Nations (UN) DDT test[10]. The regulation steel tubing is G3454 pressure-resistance type. Conventional DV measurement can be made as an average or by continuous measurement. The average method is simple, and is conventionally conducted by the Dautriche method[11], an optical method, or an electrical method. The electrical method is the easiest to perform and gives accurate results, and
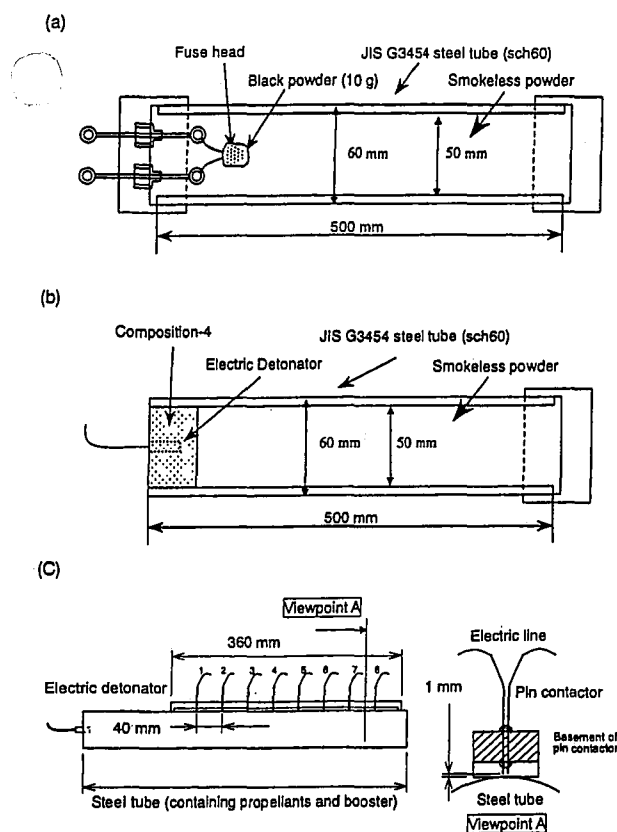
Fig.2 Schematic of charge housing with pin contactor.
(a) EBWD+C4 (b) fuse head+black powder (c)
pin contactor assembly

can be achieved by ion gap or pin contact
approaches. The ion gap method cannot be used
efficiently for propellants with high electrical
conductivity, as is the case for the smokeless
powders examined in this work, which have some
degree of conductivity even though 0.2-0.4 wt.%
graphite has been introduced to suppress the
conductivity. Therefore, the pin contact method is
adopted in this work. Figure 2(c) shows a schematic
diagram of the steel pipe and pin assembly for
measurement of DV.

Two ignition methods were employed to observe
the DDT behavior and measure the steady-state DV;
a fuse head with 10 g of black powder, or an
exploding bridgewire detonator (EBWD; RP-501,
Reynolds Industrial Systems, Inc.) with
composition-4 (C4). The function time of EBWD is
2.8 + 0.5 μs, and in this experiment was fired by a
-kV capacitor bank. The variation in DV according
to the booster was evaluated.

Three diameters of assembly (ID 27, 35.5 and 55
mm) were examined in order to investigate the
diameter effect with respect to the DV. The pin

contact assembly (Fig. 2(c)) was fitted to the steel
tube. Eight pairs of nickelized steel needles of 1 mm
in diameter were attached to a
polymethylmethacrylate (PMMA) base attachment.
The gap between the pins and the steel tube was
1.0 mm, the distance between pins in a pin pair was
1.5 mm, and the distance between pin pairs was 40
mm. Lengths were measured at 10^{-2} mm accuracy.
When the shot is fired, the steel tube deforms,
coming into contact with the pins and forming a
complete circuit that is recorded via a pulse forming
circuit. The pulses were recorded on a transient
recorder (RTD-710, Tektronix) at 10 ns resolution.

3. Results and discussion

Figure 3 shows the pin contact for the EBWD+C4
configuration in a 50/60 steel tube. Time zero is the
point at which electric current was applied to the
EBWD. After a few microseconds, the EBWD was
fired. The noise at around 10μs is due to activity of
the high-voltage (4 kV) capacitor bank. The pin
contacts recorded the procession of the detonation
wave, allowing the DV to be calculated precisely.
Table 1 shows all the results obtained in this work.

3.1. Effect of different boosters

Figure 4 shows photographs of the fragments of
the steel tube after detonation using (a) EBWD+C4
and (b) fuse head+black powder. The EBWD+C4
explosion resulted in relatively uniform, long and
thin steel fragments, indicative of steady-state
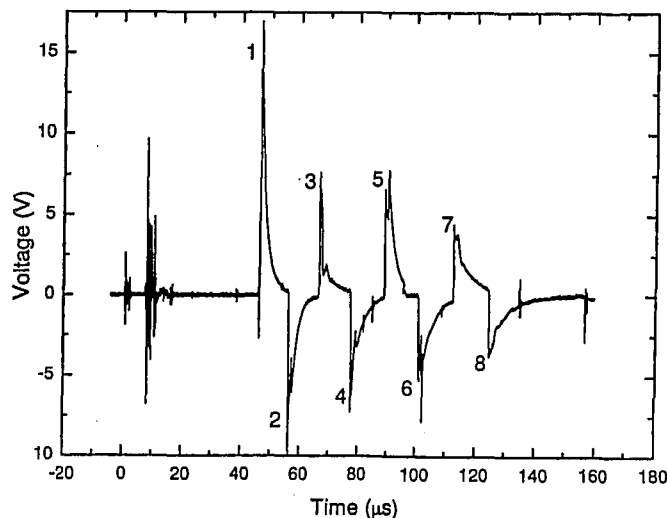
Fig.3 Electrical signal from pin contactor for 35I (DB)
with a 50/60 steel tube.

Table 1 Experimentally obtained DVs for single and double base propellants

Type of propellants	Code name	I.D.[1] (mm)	Amount of propellants (g)	Amount of igniter (g)	Charge density (g/cm³)	Experimental data		Calculated data			
								KHT		CHEETAH	
						DV(m/s)	R[2]	DV(m/s)	ΔDV[3]	DV(m/s)	ΔDV[3]
Single base	35I	27.0	142.9	23.0	0.513	3515	0.99975	3818	+ 8.6%	3833	+ 9.0%
Single base	35I	27.0	144.8	22.3	0.535	3519	0.99977	3901	+10.9%	3906	+11.0%
Single base	35I	27.0	152.4	22.5	0.563	3587	0.99992	4008	+11.7%	3999	+11.5%
Single base	35I	35.5	235.9	50.8	0.528	3477	0.99979	3875	+11.4%	3882	+11.6%
Single base	35I	50.5	528.8	10[4]	0.528	3641	0.99855	3875	+ 6.4%	3882	+ 6.6%
Single base	35I	50.5	475.7	140	0.528	3568	0.99950	3875	+ 8.6%	3882	+ 8.8%
Single base	84I	50.5	464.6	145	0.515	3537	0.99915	3804	+ 7.5%	3819	+ 8.0%
Single base	PSB	50.5	425.9	144	0.482	3377	0.99917	3698	+ 9.5%	3726	+10.3%
Single base	18s	50.5	532.7	10[4]	0.532	3334	0.99593	3868	+16.0%	3926	+17.8%
Single base	NY500	50.5	965.9	10[4]	0.964	617-1062	0.94383	5306	·	5247	-
Double base	SS	27.0	183.0	14.4	0.659	3924	0.99998	4401	+12.2%	4318	+10.0%
Double base	SS	35.5	300.6	23.5	0.627	3891	0.99999	4279	+10.0%	4212	+ 8.2%
Double base	SS	50.5	568.5	151	0.631	3962	0.99916	4294	+ 8.4%	4259	+ 7.5%
Double base	9P	50.5	595.8	153	0.661	4080	0.99974	4435	+ 8.7%	4399	+ 7.8%
Double base	M9	50.5	685.5	151	0.761	4512	0.99921	4758	+ 5.5%	4681	+ 3.7%
Double base	MJ-B	50.5	573.6	146	0.636	4047	0.99974	4321	+ 6.8%	4290	+ 6.0%
Double base	NP	50.5	579.1	149	0.643	4040	0.99958	4316	+ 6.8%	4276	+ 5.8%

[1] I.D.=Inner Diamter

[2] Correlation efficient using least-square fitting

[3] ΔDV=(Calculated data-Experimental data)/Experimental data

[4] Using black powder as a ignititer

detonation. The fragments produced by the fuse head+black powder detonation included both short, thick fragments of about 15 cm in length, and long, thin fragments. Based on this observation, the deflagration-to-detonation transition appears to have occurred at about 15 cm from the end of the tube. The same detonation with NY500 propellant had the effect shown in Fig. 4(c), where the steel tube was not significantly fragmented due to a low detonation velocity of 892 to 1062 m·s⁻¹, as seen from Fig. 5(c). It is expected that the theoretical DV of 5300 m·s⁻¹, as computed using the appropriate code,
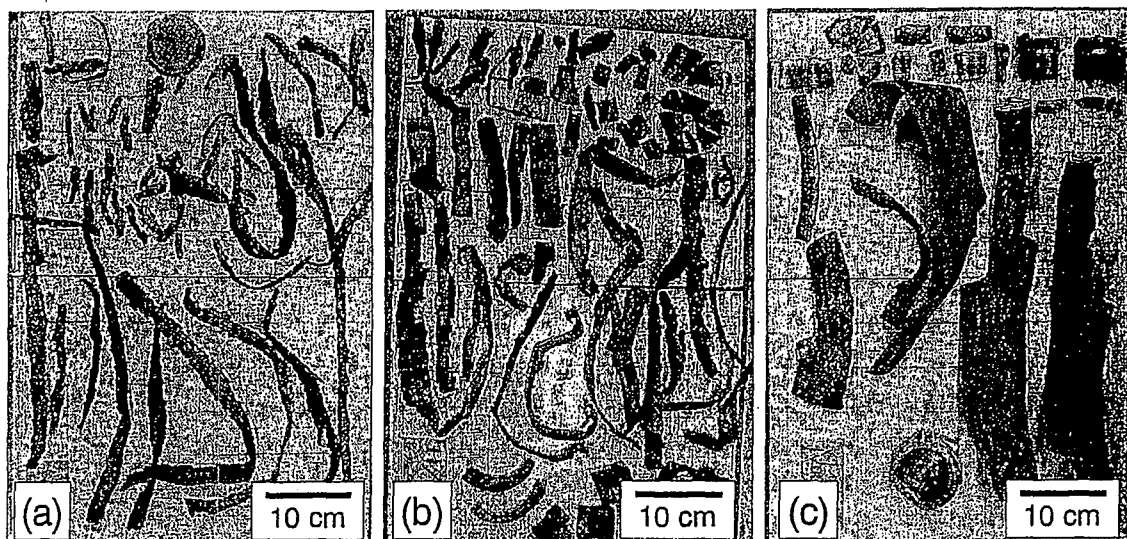
Fig.4 Photographs of steel tube fragments after detonator test for (a) EBWD+C4 with 35I at ρ = 0.528 g·cm⁻³ (b) fuse head+black powder with 35I at ρ = 0.528 g·cm⁻³ (c) fuse head+black powder with NY500 at ρ = 0.964 g·cm⁻³

Fig.5 DV measurement (x-t diagram) for(a) EBWD+C4 with 35I at $\rho = 0.528$ g·cm^{-3} (b) fuse head+black powder with 35I at $\rho = 0.528$ g·cm^{-3} (c) fuse head+black powder with NY500 at $\rho = 0.964$ g·cm^{-3}

...y be reached if the EBWD+C4 igniter is used with a far longer tube.

Figure 5 shows a DV test using (a) EBWD+C4 and (b) fuse head+black powder. Steady-state detonation appears to be achieved in the earlier stage of detonation using the fuse head+black powder detonator, for which the DV was higher than that for EBWD+C4.

The interval error is ±40μm with respect to each interval of 40 mm, and the time interval error is ± 10 ns, giving a total measurement error of less than ±0.2%. Therefore, the differences in DV are not considered to be due to measurement error, but rather from advance compression of the propellants due to preceding deflagration, which increased the DV for the fuse head and black powder.

In the case of NY500 (SB) with fuse head+black powder detonator (Fig. 5(c)), deflagration occurred between the first and fourth pins, and the steel tube was not fragmented in direct reflection of the wave front. Detonation occurred from the fourth pin, raising the DV from 617 m·s^{-1} to 1062 m·s^{-1}. However, in this case, the speed indicates the rupture speed of steel tube rather than the DV of the smokeless powder. In fact, it is difficult when using the pin

contact method to identify exactly whether the measurement indicates the rupture speed of the steel tube or the DV of the smokeless powder under these non-steady-state conditions. Therefore, in order to measure the steady-state DV, we examined EBWD+C4.

Figure 6 shows the relationship between charge density (ρ) and DV. The correlation efficient is 0.983, and the DV is strongly proportional to ρ despite the various diameters, propellants and shapes. In other words, the DV is strongly related to charge density
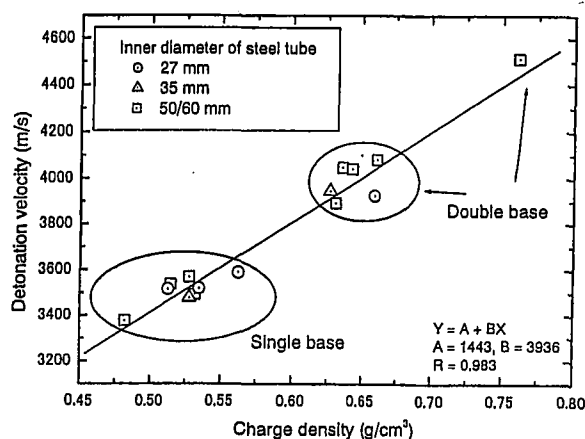
Fig.6 Density dependence of DV for single and double base propellants

rather than other properties such as chemical composition and the inner diameter of the testing tube.

3.2. Density correction using KHT or CHEETAH computational code

As it is difficult to load a consistent amount of propellant in the steel tube, the density dependence of DV was calculated after correction using KHT and CHEETAH computational code. This computation also provides theoretical calculations of the detonation and deflagration properties of pyrotechnic mixtures. The KHT code allows calculation of 900 gaseous and 600 condensed products at high pressure, and the CHEETAH code provides calculations based on the Becker-Kristiakowsky-Wilson equation of state (BKW-EOS) using data from the BKWC and BKWS databases. The BKWC database is composed of only 23 gaseous products and 2 complex products, whereas the BKWS database includes 750 gaseous products and 400 condensed reaction products. If the elemental composition, density, and heat of formation of the propellants and propellants are known, the BKW code can be used to compute C-J equilibrium detonation production composition, C-J pressure, detonation velocity, temperature, the single shock Hugoiniot and isentropy.

A least-squares fit was applied to the experimental results for the DV (Fig. 7). The correlation coefficients (R) are 0.993 and 0.996 for the KHT and CHEETAH codes, indicating that both codes are in good agreement with the experimental data. Density correction was then performed using the slopes calculated from the KHT code, allowing the DV at constant density to be determined. The slope of the experimental results (slope = 3936) was closer to the KHT calculation (slope = 3486) than the CHEETAH calculation (slope = 3236). The experimental results were therefore corrected using the KHT code by fitting a line to the KHT result and translating it to the experimental results while preserving the slope. Engelke et al[9]. introduced this method in order to achieve more accurate estimates of the DV for H_2O_2/H_2O mixtures. To investigate the "diameter effect", we compared the DV at different diameters for the same density of propellant. Figure 8 shows a schematic diagram of the density correction method. The slope of the density calculated using the computational code was used to derive the relationship between DV and charge density from the experimental data. The DV with respect to charge density was then corrected to that of object density.

3.3. Diameter effect for single and double base propellants

Figure 9 shows the DV diameter effect for single and double base propellants. After density correction using KHT or CHEEETAH code, the DV exhibits a good linear relationship with the reciprocal of the diameter. The limiting DVs for the SB and DB propellants at infinite diameter are 3624 $m \cdot s^{-1}$ and 4134 $m \cdot s^{-1}$, respectively. The experimentally DVs were lower than the calculated values by 7.1% (35I) and 4.1% (SS) for the KHT code, and by 7.1% (35I) and 3.2% (SS) for the CHEETAH

Fig.7 Calculation of DV using KHT and CHEETAH code
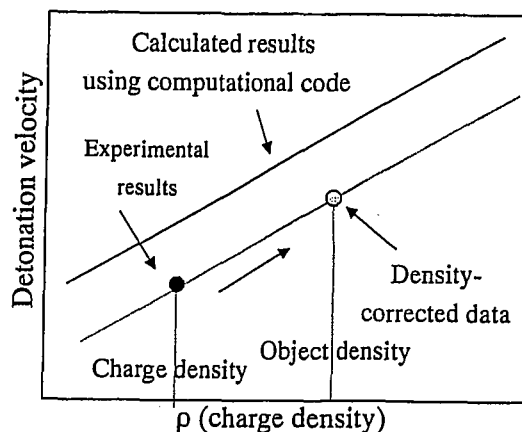
Fig.8 Schematic of density correction method
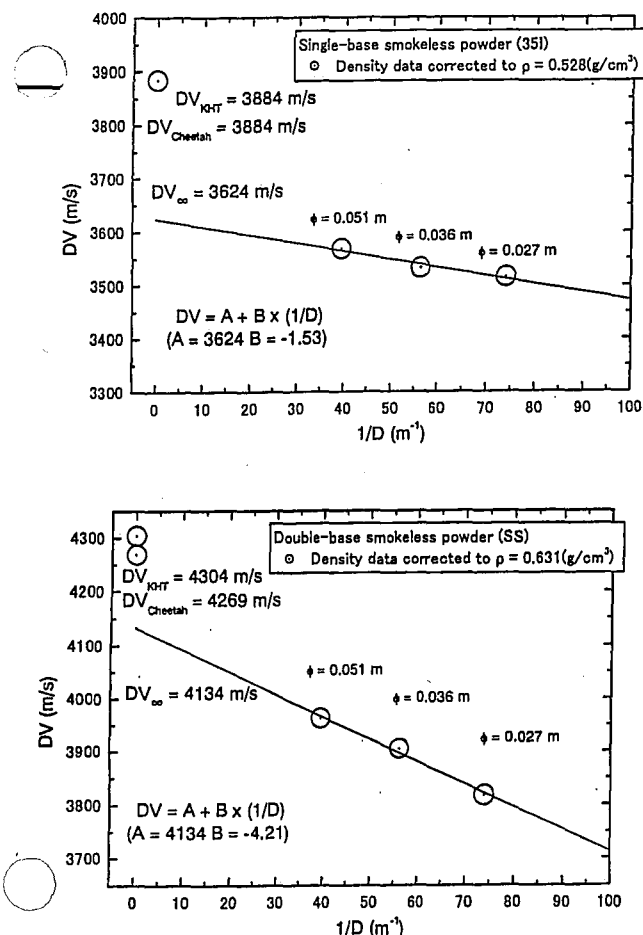
Fig.9 Diameter effect for (a) single base (35I) and (b) double base (SS) propellants

code. Mader[14] reported that the computed and experimental pressures and temperatures agree to within 20% and the DVs to within 10% for such experiments, indicating that our results are very reasonable.

In the comparison between the measured DV and the calculated DV, the following evaluation was introduced. Hobbs et al.[15] and Fried et al.[16] reported the root mean square (*rms*) error between the calculated ($D_{i,c}$) and measured ($D_{i,m}$) detonation velocities as

$$(rms) = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{D_{i,m} - D_{i,c}}{D_{i,m}} \right)^2}$$

where the subscripts *i*, m, and c represent the *i*th explosive, and measured and calculated, respectively. *N* represents the number of DV measurements, in this case 14 under steady-state DV conditions. This *rms* definition is generally used to compare calculated and measured values. In Fried et al.[16], an appropriate EOS and parameter

was introduced to minimize the *rms* error. However, in the present study, we have only estimated the validity of the calculated values. The measurement error was also estimated by Fried et al.[16]. In the case of a comparison of DVs, the measurement error is considered to be negligible.

Table 2 shows the overall *rms* error for predicting the detonation velocity of the explosives in reference [15] using the BKWS-EOS, BKWC-EOS, JCZS-small, and JCZS-large databases. In this work, the *rms* error of the 14 steady-state DV measurements was 8.8% for CHEETAH and 9.2% for KHT. This is slightly higher than that for Hobbs' results, attributable to the fact that smokeless powder is not a high explosive and contains voids to control the burning velocity. The measured DVs are considered to be in very close agreement with the calculated DVs in this work.

Table 2 Optimized *rms* error

EOS-# of gases	D[a],%	D[b],%
BKWS-132	5.1	5.2
BKWC-22	3.0	2.5
JCZS-44	2.3	2.1
JCZS-132	2.3	2.2

(a) All explosives in ref[16] (including nonideal explosives)
(b) All explosives in ref[16] excluding the nonideal explosives containing TATB and HNB

4. Conclusion

Using pressure-resistance steel tube, we found that smokeless powder can be detonated. The various conditions of DV were as follows. The steady-state DV of various propellants, using an exploding bridgewire detonator and C4, was found to be strongly related to the charge density regardless of the type of propellant. Density correction using computational code was effective, and the DVs of single and double base propellants for a charge of infinite diameter were identified as 3624 m·s^{-1} and 4134 m·s^{-1}. The computational code produced results that were highly consistent with the experimental results, indicating that the method of DV determination employed in this study

is accurate. This study demonstrated that the detonation velocity is a parameter that can be calculated and used in conjunction with other detonation parameter to assist in the prevention and diagnosis of accidents such as that at the NOF facility.

References

1) Accident investigation committee "Research report of explosion accident at 12th explosives storage facility in NOF Taketoyo plant", December 15, 2000, in Japanese

2) M.A. Zayed, A.A.-W. Soliman and M.A. Hassan. J. Hazard. Mat., B73, 237-244 (2000)

3) M.H. Sammour. Propellants, Explosives, Pyrotechnics, 23, 266-271 (1998)

4) A.Ya. Apin, I.D. Kostin and L.N. Stesik. Dokl. Akad. Nauk SSSR, 137, 652 (1961)

5) M.L. Pandow, K.F. Ockert and H.M. Shuey. fourth Symposium on Detonation, pp. 96-101, MD (1965)

6) E. James "Charge preparation for precise detonation velocity studies", Conference on the chemistry and physics of detonation (1951)

7) R.Engelke and A.W. Cambell. "The diameter effect in high-density heterogeneous explosives", Sixth Symposium on Detonation, pp. 642-652, CA (1977)

8) D. Price, A.R. Clairmont Jr., J.O. Erkman and D.J. Edwards. Combust. Flame, 13, 104-108 (1969)

9) R. Engelke, S.A. Sheffield and L.L. Davis. J. Phys. Chem. A, 104, 6894-6898 (2000)

10) United Nations "Recommendations on the Transport Of Dangerous Goods Tests and Criteria Second Edition", ST/SG/AC.10/11/REV.1

11) Encyclopedia of explosives and related items, 3, D17 (1966)

12) T. Katsumi "Detonation and deflagration properties of pyrotechnic mixtures", Decomposition, Combustion and Detonation Chemistry of Energetic Materials (1996)

13) L.E. Fried, W.M.Howard and P.C.Souers "Cheetah 2.0 User's Manual", UCRL-MA-117541 (1998)

14) C.L. Mader. "Numerical Modeling of explosives and propellants, 2nd edition", University of California (1998)

15) M.L. Hobbs, M.R. Baer, and B.C. McGee. Propellants, Explosives, Pyrotechnics, 24, 269 (1999)

16) L.E. Fried and P.C. Souers. Propellants, Explosives, Pyrotechnics, 21, 215 (1996)

THE DEFLAGRATION TO DETONATION TRANSITION OF GUN AND SMALL ARMS PROPELLANTS

- A STUDY AND REVIEW -

Contract No. 07SQ.23440-7-9157

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MINING RESOURCE ENGINEERING LIMITED

ABSTRACT

This report has been jointly produced by Mining Resource Engineering Limited, Kingston, Ontario and its sub- contractor, Thomas S. Sterling Consulting Inc., Ottawa, Ontario. The study was performed under the auspices of the Canadian Explosives Research Laboratory of the Department of Energy, Mines and Resources Canada, (Contract No. 07SQ.23440-7-9157).

Investigations performed in other countries on the deflagration - to - detonation transition (DDT) of gun and small arm propellants have shown that the tendency for a propellant to undergo the transition to detonation, depends upon such factors as composition, (percentage of nitrocellulose, nitroglycerin etc) grain size, web size, number of perforations and other physical and chemical factors. Also, the transition is affected by external factors such as the way in which combustion is initiated in the propellant, the size of the container and the degree of confinement provided by the container or propellant itself.

Some propellants are very unlikely to have a transition to detonation under conditions that exist during manufacturing, handling, storage and transport. Others have been found by investigators in other countries to have so great a tendency for transition to detonation that in almost all cases they should be classified as an explosive - i.e. as hazard division 1.1 (HD 1.1). Still other propellants under some conditions will behave as HD 1.1 and under other conditions they will behave as HD 1.3.

It is not practical to develop special quantity- distance tables for propellants. Instead, what is required is to categorize propellants as to appropriate hazard divisions under the conditions existing during manufacture, handling, storage and transport, and to take the necessary steps to ensure safety. Where it is possible to modify conditions so as to ensure that a propellant behaves as HD 1.3 instead of HD 1.1 this should be done. Quantity-distance requirements for propellants should follow the U.N. quantity-distance tables based on the hazard divisions determined for the propellants as a result of well planned studies and tests. Under no circumstances should a propellant be automatically classed as HD 1.3. However, care should be taken to ensure that it is not unnecessarily classed as HD 1.1.

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We apologize to them for any incorrect interpretations we may have made of the information, printed or verbal, which was so generously given to us and would appreciate hearing of any corrections or changes which should be made.

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THE DEFLAGRATION TO DETONATION TRANSITION OF GUN AND SMALL ARMS PROPELLANTS

- A STUDY AND REVIEW -

1.0 INTRODUCTION

Since the early 1970's at least four accidents have occurred in European countries in which propellants have burned to detonation, that is, have undergone a transition from deflagration to detonation. All of these accidents involved porous small arms propellants. In three cases the accident occurred during or just following the drying stage, possibly initiated by static electricity. The other accident occurred at the loading table during the loading of .22 inch cal. bolt pistol cartridges, possibly due to pinching or friction of propellant in the powder feeder.

In contrast to the accidents in which a fire in a propellant resulted in a transition to detonation there have been other accidents in which very large quantities of propellants, when ignited, continued to burn without explosion or detonation. The main differences between the two types of accidents appear to be that propellants which detonated were of large specific surface (or very small web) and/or were under confinement constraint while those which did not undergo transition to detonation were of a smaller specific surface (or larger web) and were under a low degree of confinement.

This report reviews findings of researchers in other countries who studied the potential of a variety of propellants to detonate under different confinement conditions. Details of work performed in these countries are given in the several appendices to this report. These include information on the tests used in the various studies and the results of those tests.

2.0 THE DETONABILITY OF PROPELLANTS

2.1 General

It is well known that propellants, when suitably initiated by an explosive source, will detonate. As in the case of all explosive materials they will have a critical diameter and an ideal diameter. Some propellants and explosives can undergo low order detonation in addition to high order

detonation. In fact this ability of propellants to detonate in low order has been used in some experimental warhead systems.

Although the ability of propellants to detonate when initiated by an explosive source was well known it was not generally appreciated that propellants, when ignited by a spark, flame or other non-explosive method under suitable conditions, can undergo a transition from combustion to detonation. The porous propellant accidents mentioned above brought wide attention to the deflagration - to - detonation transition (DDT) problem and resulted in extensive studies to develop a better understanding of the phenomenon.

2.2 TNT Equivalence

For purposes of equating blast damage from different explosives it has long been the custom to rate the output of explosives as a percentage of the output of TNT.

In studies of propellant detonation, attempts have been made to apply a similar rating system. While this is acceptable for estimating the propellant output in a large DDT accident it should not be used to reduce quantity-distance values for propellants classed as HD 1.1. If, for example a propellant must be placed in that hazard division but tests have shown that under the test conditions its TNT equivalence is 60%, there is a temptation to reduce the Q-D value. This should not be done, particularly when large quantities are involved. The larger the quantity the greater the possibility for a high TNT equivalence.

3.0 SCREENING TESTS

These tests are used by various countries for two main purposes. First, to determine the potential of different propellants for undergoing transition from deflagration to detonation. Second, for determining the hazard classification of propellants during manufacture and in their storage and transportation containers. The first are small scale tests, the second are tests using larger quantities of propellants.

3.1 Small Scale Screening Tests

Most countries have small-scale tests for preliminary screening of propellants. For the most part these are "go - no go" tests, but some also provide information on critical height for explosion or detonation, and on detonation velocity.

The main types of small-scale screening tests are:

a) <u>Small Diameter Open Tubes</u>

These are steel tubes, closed at the bottom, open at the top. Diameters are between about 40 mm and 80 mm and length from 200 mm to over 1 meter. This type of test is used by Finland and Germany as a "go - no go" test and by France and the Netherlands both as a "go - no go" test and for measurement of detonation velocity and critical height for explosion or detonation. As a simple "go - no go" test, if the tube is fragmented the sample is considered to have exploded or detonated; if the tube remains intact the sample is considered to have only burned.

b) <u>Small Closed Steel Tube</u>

The two countries using this test are France and the United Kingdom. It is primarily a "go - no go" test, however in France it is also used to provide a measure of velocity of detonation and the length of burning before the transition to detonation. In France the tubes are 41 mm I.D. X 200-1200 mm long. In the U.K. the tubes are 76 mm I.D. X 450 mm long. Both have thick walls. In France, detonation is determined by the rupture of the tube, the impression on a lead plate on which the tube rests horizontally and the measured velocity of the reaction front. In the U.K. detonation is considered to have occurred if the tube is broken into 15 or more fragments.

c) <u>Other Small Scale Screening Tests</u>

In Finland, in addition to the small diameter open steel tube test, a card gap, an open channel (trough) and a cap sensitivity test are also used for screening. These can provide some measure of relative sensitivity of propellants to DDT but should be considered more as "go - no go" tests rather than tests which provide reliable quantitative data.

3.2 United Nations Large Scale Screening Tests

All countries use the U.N. Test Series 6 large scale tests to determine the hazard division of propellants in transportation and storage containers. These are, in essence, "go - no go" screening tests where the criterion is either detonation (H.D. 1.1) or no detonation (H.D. 1.3).

3.3 Limitations of Screening Tests

Small scale screening tests, while serving to separate the more sensitive from the least sensitive propellants are generally more conservative than required. The confinement is usually not representative of the degree and type of confinement likely to occur in practice. Also, in some cases the small diameter of the tube may be less than the critical diameter of the propellant being tested.

The United Nations Series 6 tests, particularly Test 6C (Bonfire test), are valid only for the particular conditions of packaging and surrounding confinement. Changes to these have been found to produce results great enough to change a classification from HD 1.3 to HD 1.1 or vice versa.

4.0 THE INFLUENCE OF PHYSICAL AND CHEMICAL CHARACTERISTICS OF PROPELLANTS

Studies discussed in the appendices of this review report have found that most propellants, given suitable conditions, can undergo a transition from deflagration to detonation. The potential of a propellant to detonate depends on its physical and chemical characteristics, that is its "internal" characteristics, and on its "environment" such as the size of its container, its depth in the container and the confinement provided by the container.

This section discusses the influence of physical and chemical characteristics on detonation potential. The next section will consider the influence of environment.

4.1 Influence of Specific Surface and Density

All four of the recent accidents in which propellants burned to detonation involved porous propellants. The probable cause of three of these accidents was static electricity.

Porous propellants are single base propellants in which potassium nitrate has been incorporated into the solvent-wet mix and then dissolved out of the propellant grain. The pores are apparently interconnected.

These propellants have a low density and a high specific surface. Densities may range from about 25 per cent of theoretical maximum density to about 75 per cent. Typically a porous small arms propellant may have a specific surface including pores of about 50 m^2/kg.

Because of its large surface a porous propellant could be expected to have a higher rate of burning than a comparable non-porous propellant. This, in turn, could be expected to result in a higher rate of build up of pressure and a lower critical explosion height (CEH). In one reported series of tests (Appendix E) a porous propellant in a 30 cm I.D., 32 cm O.D. container was found to have a CEH of 40 cm while, under the same conditions, a non-porous propellant had a CEH of 50 cm.

The porous propellant was single-base, single-perforated, short- tube with a web of 0.34 mm, a density of 0.32 g/cm^3 and a specific surface of 48.2 m^2/kg.

The non-porous propellant was very similar to the porous propellant except for its specific surface, and density. It was a single-base, single-perforated, short-tube propellant with a web of 0.33 mm, a density of 0.92 and a specific surface of 5.2 m^2/kg.

One would expect that with such a large difference in the specific surfaces of the two propellants there should be a greater difference in the Critical Explosion Heights (CEH). The answer perhaps lies in the relatively large web of the porous propellant, and thus the limited accessibility of the surfaces of the pores to flame. Also, the porous propellant, by its low density provides less self confinement than the non-porous propellant.

4.2 Influence of Web Size

In non-porous propellants, web size is clearly related to specific surface. Propellants with small webs will have large specific surfaces and for the same form and composition a higher rate of burning. They could therefore be expected to have lower CEH's than propellants with large webs.

Studies performed in France and reported here in Appendix B show a strong dependence of critical explosion height (CEH) on web size. A single-base non-porous propellant with web size 0.2 mm was found to have a CEH of about 0.2 m. The same propellant with a web size of 0.4 mm had a CEH in the same test (200 mm diameter open tube) of 0.85 m. The correspondence between web size and CEH is linear.

In the Netherlands, (Appendix D), it has been determined that finished porous propellants in web size smaller than 0.19 mm (0.0076 in) should always be classified as HD 1.1.

In the Netherlands and the U.S., double base propellants with web smaller than 0.19 mm are classified as HD 1.1. Further information is given in the tables of Appendices D and G.

4.3 Influence of Heat of Combustion

Porosity and web size are, indirectly, measures of surface area available to the flame for burning a propellant. That is, the rate of burning of a propellant depends to a considerable extent on this available surface area. Another factor which will influence the rate of burning is the heat liberated when the propellant burns. A propellant with a high heat of combustion will produce gases at a higher temperature than a propellant with a low heat of combustion. The high temperature accelerates the rate of burning, and if the propellent is confined to any appreciable degree, the pressure in the burning bed. This further accelerates the rate of burning.

Studies performed at SNPE are discussed in Appendix B. These show that the Critical Explosion Height decreases rapidly with increasing heat of combustion.

It should be noted that the heat of combustion of a propellant depends on its composition. A propellant made with high nitrogen nitrocellulose will have a heat of combustion greater than one made with a low nitrogen nitrocellulose. A double base propellant containing nitroglycerin will have a heat of combustion greater than a single base propellant.

4.4 Combined Effects of Density, Web Size and Heat of Combustion

In the above discussion it has been noted that the critical explosion or detonation height of a propellant depends, to a considerable degree, on its density, web size and heat of combustion.

As density decreases the critical height for explosion decreases.

As web size decreases the critical height for explosion decreases.

As the heat of combustion increases the critical height for explosion decreases.

4.4.1 The "R" Factor

In France, Goliger and Lucotte have combined these three parameters to create a factor "R", against which they have plotted the CEH for a large number of propellants including single base porous and non-porous propellants and double base propellants. The factor R is defined as:

$$R = \frac{\text{Heat of Combustion (cal/g)}}{\text{Web (mm) x Bulk Density (kg/m}^3)}$$

Their graph of R versus CEH is copied as Figure 5 of Appendix B of this review report. It shows an exponential decrease in CEH with increase in R.

The CEH values used in this graph were measured in a 200 mm I.D. open tube. Because of the relatively small tube diameter the curve can not be used to determine from a propellant's "R" value its CEH in other containers. However the CEH values from the 200 mm open tube test are conservative and can be used to provide an estimate of the lower limits of CEH for propellants in larger containers.

4.4.2 Vivacity

Vivacity is the intrinsic rate of burning of a propellant and is usually taken as the rate of change of pressure with pressure.

$$\text{Vivacity A} = \frac{(dP/dt) \, Pa}{Pa \, Pm}$$

where Pm is the maximum pressure

Pa is the pressure at where dP/dt is measured

This is usually determined by measuring dP/dt at 5 different levels of pressure, Pa, on the rising part of a pressure vs time curve. The measurements are performed in most countries by burning

140 g of the propellant in a standard 700 ml closed vessel (see Appendix D and references therein).

In the Netherlands vivacity is used in conjunction with information on web size, propellant composition and number of perforations to estimate the height of propellant, in standard process and storage containers, above which transition to detonation can be expected to occur (Figures 1 to 6 of Appendix D).

The combination of Vivacity with other physical and chemical properties of a propellant, as is done in the Netherlands, seems to be the most useful method of predicting critical height in process and storage containers.

In Finland, vivacity is used as a test to measure the potential of a propellant to undergo transition to detonation. Propellants with high vivacity have a greater tendency to undergo this transition or undergo it at a lower critical height than propellants with a low vivacity.

5.0 THE INFLUENCE OF PHYSICAL ENVIRONMENT

Environment, in this context, includes the confinement given to a container of propellant by the cross-sectional area of the container, its material and wall thickness, its venting area and by the height of the propellant in the container. It also includes, to a limited degree, the temperature of the propellant.

Although all countries have pointed out that container size, wall thickness and depth of propellant have a strong bearing on whether, in a particular case, a propellant will detonate there is little concrete test data available.

The best data are from papers published by a Swiss researcher, Frauenfelder, discussed in Appendix E of this study review. Frauenfelder's conclusions were:

1) In a mildly ignited propellant charge no transition from deflagration to detonation will occur provided that at least one of the following two conditions is met:

    A) the container has a weak point near the point of ignition, such that the weak point will open at a sufficiently low pressure to allow propellant and combustion gases to escape.

B) the height of the bed in an open container is less than the critical height of the bed.

2) The critical height of the bed depends largely on the specific surface of the propellant and to some degree on the propellant temperature.

Point 1 A) above is very important. It means that if self- venting of the container can occur by rupture at a low pressure the contents will not undergo transition to detonation. In the U.S.A., process containers have been designed with a high degree of venting area in order to reduce the potential for detonation (Appendix G). In this regard it should also be pointed out that two massive fires in propellant blending towers in the USA in 1944 did not progress to the detonation stage, possibly because the fires started at the top of the towers, permitting a high degree of venting.

6.0 CONCLUSIONS

1) Most propellants, under suitable conditions, can be made to undergo a deflagration (burning) - to - detonation transition. .

2) The potential of propellants to burn to detonation is greatest for propellants having the following physical or chemical characteristics:

   a) high specific surface (porosity)

   b) small web

   c) high energy - eg. double base propellants containing nitroglycerin

   d) multi perforated form

   e) high heat of combustion

   f) high vivacity

   g) low density or low bulk density

3) The potential of a propellant to burn to detonation is increased under the following conditions:

    a) high degree of confinement provided by the container.

    b) violent ignition

    c) self confinement provided by a high height of propellant bed

    d) restricted venting of propellant gases from the container, allowing rapid build-up of pressure in the container

    e) high initial propellant temperature

4) The hazard classification of a propellant should be commensurate with its potential to undergo deflagration to detonation transition and with the height of bed at which this transition occurs under the manufacturing, storage or transport conditions which apply.

5) Under some conditions a propellant should be classed as HD 1.1 and under other conditions as HD 1.3.

6) There is insufficient information on how propellants should be stored in magazines and other storage buildings so as to minimize the potential for build up to detonation of large quantities. Factors to consider include spacing between containers or rows of containers, stacking, and venting.

7.0 RECOMMENDATIONS

1) A catalog should be prepared of all types of propellants made in Canada or imported into this country.

2) All operations involved in the manufacture of propellants in Canada should be reviewed to determine if a potential hazard exists from the point of view of excessive height of propellant bed (for example in driers).

3) All operations involved in the manufacture of propellants in Canada should be reviewed to determine, for each propellant, the hazards from static electricity.

4) All propellant loading operations, particularly of small arms propellants, should be reviewed to ensure that the confinement in loading tubes and hoppers, and the depth of propellant in hoppers does not exceed safe values.

5) Steps should be taken to ensure that allowable propellant depths in containers used for storage and transport are appropriate for the propellant (type, web, etc.) and for the confinement conditions imposed by the container.

6) If necessary, tests should be carried out to determine the critical detonation heights of propellants in the containers used in manufacturing, storage and transport in Canada.

7) A study should be performed to determine safe methods for storage of large quantities of propellants.

8) Quantity-distance tables for propellants should be the existing U.N. Q-D. Table 1 for propellants classified as H.D. 1.1 and Table 3 for propellants classified as H.D. 1.3.

9) The TNT equivalence of a propellant should not be used to modify Q-D Table 1 distance values.

10) The methodology used in the Netherlands for catergorizing propellants for manufacture should be considered for adoption in Canada. This methodology is described in Appendix D and shown diagrammatically in Figures 1 through 5 of that Appendix.

A P P E N D I X   A

FINLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

FINLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

As a result of a major accident in a small arms propellant loading plant in 1976 at Lapua, Finland completely revised its Explosives Act and Explosives Regulations (1980). Finland also carried out extensive studies of the sensitivity of propellants and of their potential for burning to detonation.

The tests which were found to be most indicative of a propellant's potential for deflagration-to-detonation transition were:

- Closed vessel vivacity

- Card gap

- Open channel (Trough)

- Cap Sensitivity

- Steel Tube (Open Tube)

Of these:

a) the steel tube test is a means of obtaining a quick "go - no go" indication of transition potential;

b) the closed vessel vivacity test provides a scientifically measured value which, together with web size and composition can be used to provide a reasonably quantitative measure of the transition potential and hence of critical height of propellant for explosion or detonation.

1.0 ACCIDENTS

There has been one instance of explosion or detonation of a propellant in Finland. This was at the Lapua Cartridge Factory on 13 April 1976. The propellant primarily involved was a Nobel CK N04 small arms propellant 62.7% NC, 36.3% NG used for loading 0.22 inch Cal. "bolt pistol" cartridges. A total quantity of about 700 kg of propellants detonated.

The investigation found that the most probable starting point of the detonation was in a packing groove beside the "dosing" cup which measured the propellant into the cartridge. From this loading table position, flame could proceed up the loading tube to the powder loading hopper and, making the transition to detonation, could initiate detonation in nearby boxes and other hoppers. The loading loft contained N310, N340 and N140 single base propellants in addition to the CK NO4 propellant.

2.0 SEALED TUBE REACTION RATE

This test was carried out as part of the Lapua Accident investigation[1,3]. The apparatus was a brass tube 39mm I.D., 42mm O.D. and 1.2 m long. It was completely closed at the lower end. The upper end was closed with a flange that had a central hole 10 mm in diameter through which the propellant, was ignited by an electric squib.

The materials tested were those which were present in loading bays, the powder loft at the time of the accident and also F65/75 black powder.

Results are shown in Table 1. The N310 and N340 are single base porous propellants, N140 is a single base non-porous propellant and Nobel CK NO4 is a double base (63/36 NC/NG) non-porous propellant.

The tube used in this test was of the same material and inside and outside diameters as the powder tube leading from the powder loft hopper to the loading table.

POWDER	REACTION RATE MAXIMUM ATTAINED (m/s)	LENGTH TO ATTAIN DETONATION (cm)	TIME TO ATTAIN DETONATION (ms)	NOMINAL THICKNESS (mm)	WEB	
					(mm)	(inches)
N 310 SB Porous Short Cylinder	3800	12-25	10-20	0.6	0.6	0.024
N 340 SB Porous Single Perforation	3200	12-25	10-20	0.8	0.25	0.010
N 140 SB Non-Porous Single Perforation	500	NO DETONATION		0.7	0.5	0.020
Nobel CK No 4 DB Non-Porous Disc 0.9X0.5mm	3900	12-25	10-20	0.5	0.5	0.020
Black Powder F 65/75	294	NO DETONATION				

SB = single base
DB = double base
The density of N 310 powder was 0.48 g/cm^3 and the density of N 340 powder was 0.56 g/cm^3.

TABLE 1: SEALED TUBE REACTION RATE

3.0 SMALL SCALE STUDIES AND TESTS

Since the Lapua accident, the Kemira Oy company and the Research Centre of the Finnish Defence Forces have studied several test methods to attempt to characterize 32 different single, double and triple based propellants[2]. The test methods were: fallhammer, friction, spark sensitivity, rifle bullet, steel tube, cap sensitivity, card gap, open channel and closed vessel vivacity tests.

Of these the fallhammer, friction, spark sensitivity and rifle bullet tests were found to be unsuitable.

Cap sensitivity and steel tube tests appeared to be suitable as screening tests to indicate the potential of a propellant to burn to detonation. Card gap, open channel (ie trough) and closed vessel vivacity tests were considered to be the best for accurate characterization.

Unfortunately, the results available to us identified the propellants only by type and did not give data on composition, web size or density. However, the correlations noted above are quiet evident. Table 2 is from a paper presented by A. Maki and A. Kariniemi at the 17th International Annual Conference of ICT, 1986, Karlsruhe[2].

Limited data is available from other sources[1] on some of the propellants (see Table 1).

N 310 is a porous single base, short cylinder propellant of nominal length 0.8 mm and nominal "thickness" 0.6 mm (0.024 inches).

N 340 is a porous single base, tubular propellant of nominal length 1.2 mm and nominal "thickness" 0.8 mm (0.032 inches).

N 140 is a non-porous single base tubular propellant of nominal length 1.25 mm and nominal "thickness" 0.75 mm (0.030 inches).

These three propellants were in the powder loft at Lapua at the time of the explosion. From Table 2 it would appear that N 310 and 340 will be prone to burning to detonation and that N 140 may be borderline safe. This is supported by the test results shown in Table 1.

POWDER TYPE	CLOSED VESSEL VIVACITY (sec^{-1})	CARD GAP (cm)	OPEN CHANNEL (m/sec.)	CAP SENSI-TIVITY	OPEN STEEL TUBE
N312	3,9	0,0	0,29	+	+
N310	3,3	6,3	0,30	+	+
N320	2,7	6,4	0,21	+	+
N340	2,2	6,7	0,20	+	+
N335	2,0	6,4	0,22	+	+
10B27	1,7	8,2	0,16	+	-
3N36	2,8	6,5	0,13	+	+
N330	1,7	6,8	0,22	+	+
N331	1,4	7,2	0,22	+	+
15B59	1,3	8,2	0,14	+	-
N110	1,1	4,7	0,15	-	-
10B33	0,7	3,4	0,20	+	-
N120	0,8	3,7	0,15	-	+
N133	0,7	3,4	0,14	-	-
N140	0,5	3,5	0,15	+	-
15B43	0,7	3,3	0,13	+	-
N130	0,7	3,6	0,10	-	+
N160	0,5	3,0	0,13	-	-
N135	0,6	3,1	0,11	-	-
N165	0,5	3,0	0,11	-	-
N125	0,6	3,8	0,05	+	-
11B75	0,4	2,5	0,13	-	-
2N15	0,4	0,3	0,19	+	-
11B41	0,3	2,3	0,05	-	-
6B8	0,1	2,3	0,04	-	-
9D1	0,04	0,8	0,10	-	-
11B37	0,1	0,0	0,13	-	-
14D91	0,1	0,0	0,12	-	-
13N24	0,1	1,1	0,06	-	-
14D9	0,04	0,2	0,08	-	-
11B60	0,1	0,8	0,04	-	-
25N42	0,2	0,2	0,05	+	-

TABLE 2: THE RESULTS OF VARIOUS TESTS BY KEMIRA OY

The laboratory scale tests most appropriate to propellant detonation studies are:

a) cap sensitivity and open steel tube tests used for screening;

b) card gap, open channel and closed vessel tests used in Finland for characterization.

These are described below from the data of Maki and Kariniemi cited above.

3.1 Cap sensitivity test

The cap sensitivity test is performed as follows. One kg of the propellant to be tested is put into a plastic bag. This bag is hung in free space at a level of one meter above the ground. The charge is initiated with no. 8 electric cap at the centre of the sample. An explosion or detonation is considered to have occurred when no remains of unburnt propellant are found on the ground. If a sample fails to detonate on the first test, two more cap sensitivity tests are carried out.

3.2 Steel tube test (open tube)

The steel tube used in the test is 350 mm long with a welded steel sheet measuring 100 X 100 X 3 mm at the bottom end. The external diameter of the tube is 50 mm and the wall thickness 3 mm. Through the tube is drilled a hole with 5 mm diameter for ignition at a distance of 50 mm from the bottom. Through these holes is put a sparkler stick and the tube is filled with the propellant to be examined. The tube stands on the ground with the open end pointing upwards as it is ignited. The sparkler stick ignition system was chosen due to slow burning rate.

Each propellant is tested three times. The burning always results either in the total fragmentation of the tube or the tube remaining intact.

3.3 Large scale gap test

The gap test gives an indication of the relative sensitivity of the explosive or propellant to a shock wave.

The donor charge used in the tests consists of two pressed tetryl boosters measuring D 49.8 X 25 mm. The density is 1.51 g/cm^3 and the weight 73.5 g. These are initiated by a No. 8 electric cap.

1-10 mm thick PMMA (polymethylmethacrylate) sheets are used as the barrier (gap) medium. The propellant under study is put into a 140 mm long seamless metal tube with external diameter 48.3 mm and internal diameter 37.1 mm. The witness plate is a steel plate measuring 10 X 100 X 100 mm. Between the witness plate and the tube there is an air gap of 1.6 mm. The test equipment is attached to a wooden frame so that the witness plate lies on the frame supported at the edges. The center, where the steel tube stands, is left free.

The barrier (gap) thickness that gives a transmission probability of 50% is determined.

3.4 Open channel test

In the open channel test the burning velocity is measured in an open right angled channel. The total length of the channel is 1.3 meters and the channel width is 15 cm. There are two holes in the channel at a distance of one meter from each other and a height of 15 mm from the bottom of the channel. The detectors of a time interval counter are placed in the holes. The detectors are made of two thin isolated copper wires twisted together.

The propellant is laid along the whole length of the channel as a 2.5 cm thick layer. The propellant is ignited at one end by safety fuse. The start and stop pulses are received by an interval counter.

3.5 Closed vessel test (vivacity)

The closed vessel used in Finland for vivacity measurements has a 200 ml volume while the NATO standard is now 700 ml. The smaller vessel is used at a loading density of 0.1 g/ml while the loading density for the larger vessel is 0.2 g/ml. The propellant charge is ignited with 2 g of black powder and an electric fuze head. Pressure versus time is measured with a quartz gauge and vivacity is determined as the rate of change of pressure with pressure. Vivacity is, essentially, the intrinsic rate of burning of a propellant.

It is clear from Table 2 that the tendency for transition from deflagration to detonation is greatest at the higher values of vivacity.

In Finland, vivacity is used as one of a number of tests to determine the potential of a propellant to undergo transition to detonation. In the Netherlands, the other country which uses this test

for deflagration to detonation studies, vivacity is used, in conjunction with other physical and chemical properties, to estimate critical heights for detonation in process and storage containers.

4.0 LARGE SCALE TESTS

Finland uses the U.N. Test series 6 to assist in determining the hazard divisions for explosives and propellants but also makes use of laboratory tests for propellant classification and particularly for pyrotechnic compositions. We did not find out if any large scale tests other then U.N. Test Series 6 were used to determine an "in process" hazard division for propellant.

5.0 PRECAUTIONS

Quantities of propellant at all stages are kept as small as possible and operations are separated from each other by very conservative safety distances. The two most hazardous operations are propellant loading and propellant drying. Loading operations have been completely changed since the explosion: to minimize the amounts of propellant in loading hoppers and loading tubes; to prevent transmission of flame or detonation in loading tubes; to isolate loading hoppers from each other; and to minimize the amount of propellant in the loading loft. In propellant drying - the quantity of propellant is limited to 400 kg, considered to be a safe quantity for the size of container and height of propellant in it.

Safety distances inside the plant for materials that are determined to be in HD 1.1 are between 2 and 5 times greater than the safety distances proposed in the NATO AC/258 tables.

REFERENCES

1) Jorma Karhulahti, (Inspector of Explosives Finnish Ministry of Defence) "Report of the Explosion Accident at the Lapua Cartridge Factory in Finland, 13th April 1976".

2) A. Maki and A. Kariniemi "Testing and Evaluation of the Handling safety of Propellants" - paper presented at the 17th International Annual Conference of ICT, June 25-27, 1986, Karlsruhe.

3) A. Maki and J Kuortti "Investigation of An Explosion at a Cartridge Loading House". International Exchange of Experience on Industry-Connected Accidents of the Explosives Industries VI Congress - Sevilla 1978.

A P P E N D I X B

FRANCE

STUDIES OF PROPELLANTS - BURNING TO DETONATION

FRANCE

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

An accidental ignition of a single-base porous propellant in a propellant drying container at the French National Gunpowder Factory, Pont-de-Buis, in 1975 caused the propellant to burn to detonation and triggered a series of similar detonations at other locations in the plant. A total of about 12 tonnes of propellant detonated, creating damage equivalent to about 7 tonnes of TNT.

Over the next 4 years a comprehensive study was conducted to determine the factors which might cause a propellant to detonate.

Small scale tests, mainly in open tubes of two sizes, 82.5 mm and 200 mm, established that the critical heights for explosion and detonation of propellants depended primarily on web size and heat of combustion for the same bulk density, confinement and surface finish. These latter three factors were also found to have significant effects on critical heights for explosion and detonation.

Large scale tests, in which confinement was considerably less than in the small scale open tube tests, showed that critical heights for explosion and detonation were considerably greater than critical heights found in the small scale tests. A significant number of large scale tests have been performed since 1979 to ensure that heights of propellants in hoppers, drying bins and storage containers will be well below critical explosion heights for all propellants.

Propellant web, composition and vivacity have been found in other countries to have a major influence on the potential of propellants to undergo transition from deflagration to detonation. In France a collective factor "R", incorporating web, heat of combustion and bulk density is used to draw conclusions as to critical explosion height of propellants.

1.0 ACCIDENTS

A major accident occurred at the National Gun-Powder Factory, Pont-de-Buis on 7 August 1975. This factory mainly produces single-base propellants for ammunition for light and medium calibre weapons and for sporting rifles. There were a series of explosions which killed 3 workers and injured 64. Studies estimated that 12 tons of single base powder detonated causing damage equivalent to that from about 7 tons of TNT high explosive. The propellant which initiated the accident was a single base porous powder of web 0.3mm (0.012 inches), density 0.5 g/cm^3. The explosion apparently started in a propellant drying container and spread by means of projected metal particles to other containers. There was a delay of 75 sec between the first explosion and further explosions.

As a result of this accident the French Government embarked on a comprehensive study of the factors which might cause a propellant to explode or detonate. This study was mainly carried out by La Societe National des Poudres et Explosifs at the Centre de Recherches du Bouchet. The principal investigators were Mr. Jean-Paul Lucotte[1,2] and Mr. Jean Quinchon[1].

When the factory was rebuilt larger separation distances were used between buildings and processes were modified. In particular, care was taken to ensure that a propellant in drying containers, storage containers, hoppers and other equipment would be as lightly confined as possible and the heights of propellant in these containers would always be below what trials had shown would cause burning to progress to explosion or detonation.

2.0 TESTS TO STUDY THE TRANSITION BURNING-TO-DETONATION

In France several tests are used to study the deflagration (burning) to detonation phenomena in propellants. Each test yields useful results and has its advantages and disadvantages. Each answers some questions but leaves others unanswered.

2.1 Small Scale Closed Tube Test

This is a test which is used to determine the distance required for burning to progress to detonation when a propellant is ignited in a small diameter tube under heavy lateral and end confinement. It serves several purposes; a) to determine if a propellant under confinement is

likely to burn to detonation; b) to measure the pre-detonation length, ie, the distance, after ignition, required for the transition to detonation; c) to measure the detonation velocity attained. This information is useful, among other things, in the design of loading systems for small arms propellants.

The steel tube is 41 mm ID, 49 mm OD and is closed at both ends by screwed caps. Through one cap is a small hole carrying a continuous velocity measuring probe and through the other is a hole to cary the wires for a small igniting charge. This consists of 10 g of fine propellant powder and a small electrical squib. The usual length of the tube is 300 mm but variations are 200 mm and for propellants with a long pre-detonation length, 1,200 mm.

In the test, as illustrated in Figure 1, the tube lies horizontally on and in close contact with a heavy lead plate. The point of onset of detonation is depicted by the location of the heavy impression on the lead witness plate made by the bursting tube. The velocity of that detonation is measured by the probe.

The disadvantages of this test are:

a) The confinement is not representative of the degree and type of confinement likely to occur in practice.

b) The small diameter of the tube may be less than the critical diameter of the propellant being tested.

3.0 TESTS FOR CRITICAL HEIGHT

Goliger and Lucotte[1,2] have conducted extensive investigations of deflagration to detonation behaviour of propellant powders in vertical tubes open at the top end and ignited at the lower end. Experiments were performed with tube diameters between 50 mm and 1600 mm, but mainly in two diameters, 82.5 mm and 200 mm. For the most part the wall- thickness was such that the calculated static resistance of the tube was less than 400 bars (5800 psi).

PROPELLANT

SQUIB AND
IGNITOR

LEAD   BLOCK

VELOCITY PROBE
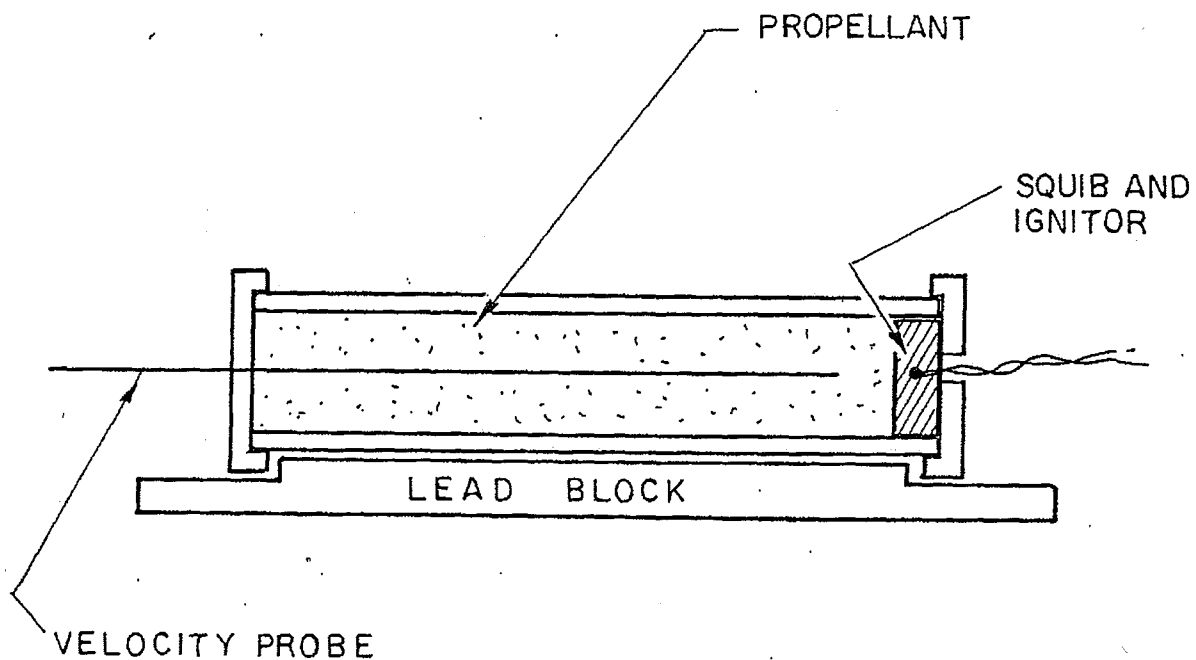
FIGURE 1 :   SMALL CLOSED TUBE TEST (AFTER GOLIGER & LUCOTTE).

In each series of tests the main parameter which is varied is the height of the bed of propellant powder.

In practice it was found that below a certain height of bed the phenomenon observed was non-violent (ie, combustion). As the height of bed was increased a level was reached where the reaction became violent and could be characterized as an explosion. As the height of bed in the series was increased still more a second level was often reached above which the powder was found to detonate. The first (explosion) level was called "critical explosion height" (CEH) and the second (detonation) level was called "critical detonation height" (CDH).

Ignition in the open tube tests is by a heated wire at the base of the tube.

In developing the tests the parameters studied included[2]:

- type of initiation

- position of the point of initiation

- thickness of the wall of the tube

- diameter of the tube

As noted above, the study resulted in the choice of two diameters of tube as more or less standard, 82.5 mm and 200 mm.

4.0 RESULTS OF OPEN - TUBE TESTS

Lucotte[2] reported in considerable detail at an ICT Conference in 1979 at Karlsruhe on the findings of his studies. These results, taken from his technical paper are summarized below.

4.1 Effect of tube diameter on Critical Explosion Height

This study was performed with a single-base non-porous powder in short stick form. In all cases the tube wall thickness was 1.2 mm. The results show that the Critical Explosion Height increases as the tube diameter is increased. This can also be considered to show that the Critical Explosion Height decreases as the static resistance (confinement) of the tube increases.

The results are shown in Figure 2 (after Lucotte). At the largest diameter studied the sample was considered to have detonated. This result, from a single test, is regarded as tentative.

4.2 Comparison of Results for 82.5 mm and 200 mm Diameter Tube Tests

Results by Lucotte have shown that tests in the 82.5 mm ID, 88.9 mm OD tube are more severe than in the larger diameter tube. The Critical Explosion Heights in the smaller diameter are, on the average, about 2.5 times smaller than the CEH's found in the larger diameter tube tests. This is primarily because the static resistance of the smaller diameter tube is greater than that of the larger tube. Lucotte's results are shown in Table 1.

4.3 Comparison of Critical Explosion Height (CEH) and Critical Detonation Height (CDH)

Studies by Lucotte show that propellants which, in the tube test, have a small CEH also have a relatively small CDH and those with a larger CEH may have a very large CDH. Results of tests in 200 mm ID tubes are shown in Table 2.

4.4 Influence of Web size on Critical Explosion Height

To determine the effect of web size on the Critical Explosion Height, a number of tests were carried out in 200 mm diameter tubes, of non-porous "B" powders. The web of a propellant is the shortest distance between two burning surfaces. In flake propellant the web is the thickness of the flake; in tubular propellant the web is the thickness of the wall. Thus a propellant with a small web will have a larger burning surface area than one with a thicker web and can be expected to burn more rapidly. As might also be expected the Critical Explosion Height is smallest for the smallest webs. As illustrated in Figure 3, after Lucotte.

4.5 Influence of Heat of Combustion on Critical Explosion Height

Propellant powders have different intrinsic energies depending on their constituents. A Ballistite, 60/40 nitrocellulose/nitroglycerin, will liberate more heat on burning than will a single base propellant containing mainly nitrocellulose. Lucotte has conducted tests, in the 200 mm diameter tubes, on propellants of similar web size but with heats of combustion from 700 cal/g to about 1200 cal/g.
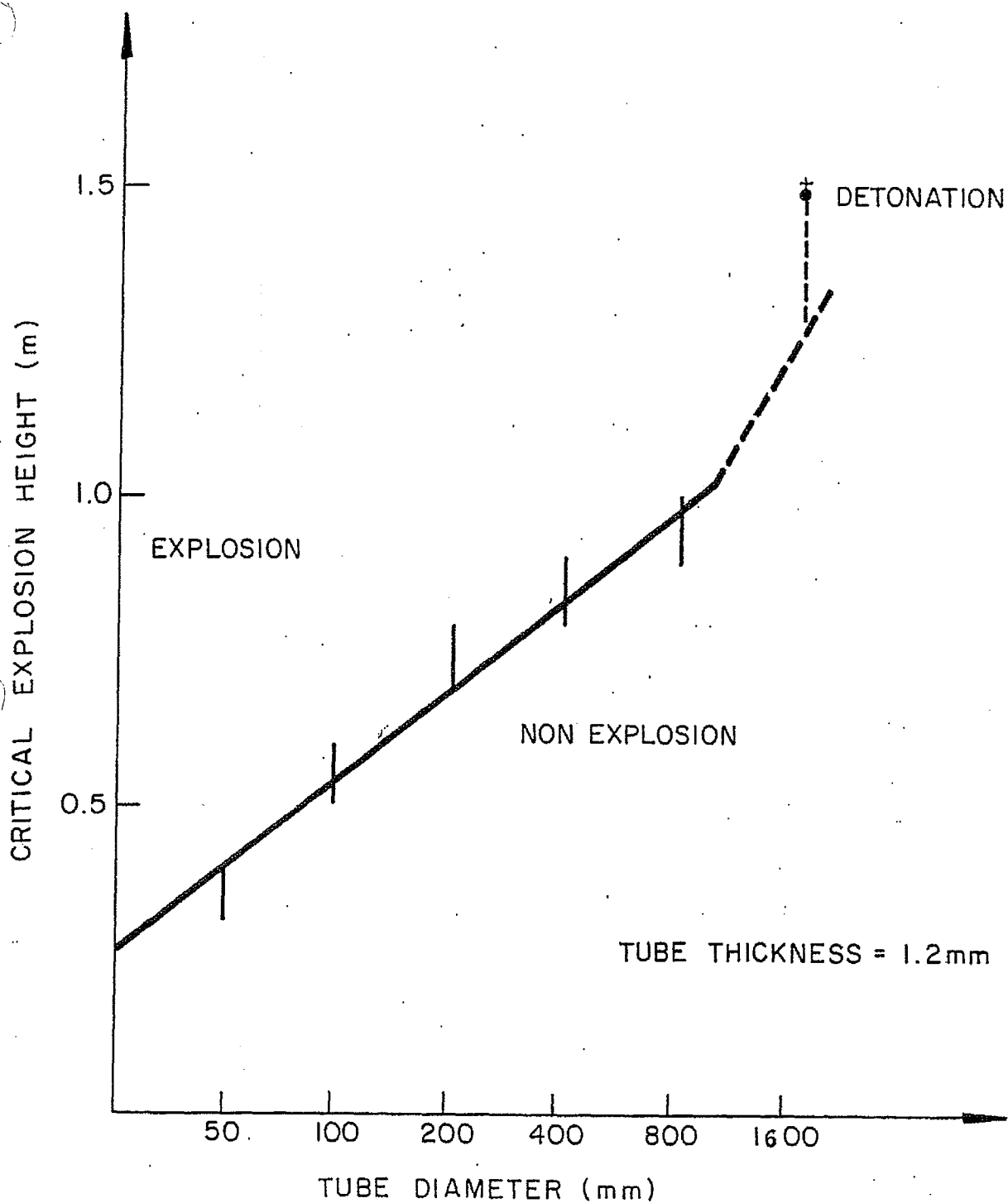
FIGURE 2 : CRITICAL EXPLOSION HEIGHT AS A FUNCTION OF DIAMETER
POWDER - IN SHORT STICKS.[2]

| TEST | CRITICAL EXPLOSION HEIGHT (m) | |
| | TUBE 200 mm ID 202.4 OD | TUBE 82.5 mm ID 88.9 mm OD |
PROPELLANT		
T	0.4 - 0.5 m	0.25 - 0.35 m
B short stick	0.7 - 0.8	0.4 - 0.5
B tubular	0.9 - 1.0	0.15 - 0.25
Ballistite	0.3 - 0.4	0.10 - 0.15
Ball Powder (coarse)	0.5 - 0.6	0.35 - 0.40
Ball Powder (a) crushed	0.2 - 0.3	0.15 - 0.25
Ball Powder (b) crushed	0.1 - 0.2	< 0.1
Ball Powder (c) crushed	0.4 - 0.5	0.25 - 0.35

NOTE: All powders are single base except ballistite which is about 60/40 NC/NG

TABLE 1: LUCOTTE'S RESULTS.

PROPELLANT	CRITICAL EXPLOSION HEIGHT (m)	CRITICAL DETONATION HEIGHT (m)
B non porous	0.5 - 1.0 m	> 1.8 m
B porous	0.3 - 0.4	0.5 - 0.9
LB	1.0 - 1.1	> 1.8
Ballistite - fine	0.2 - 0.4	0.2 - 0.4
Ball Powder - fine	0.1 - 0.3	0.2 - 0.8
Ball Powder-coarse	0.5 - 0.6	> 1.8

NOTE: L.B. POWDER IS A "COOL BURNING" POWDER i.e. a powder with a low combustion temperature.

TABLE 2: COMPARISON OF CEH AND CDH VALUES, 200 mm TUBE.
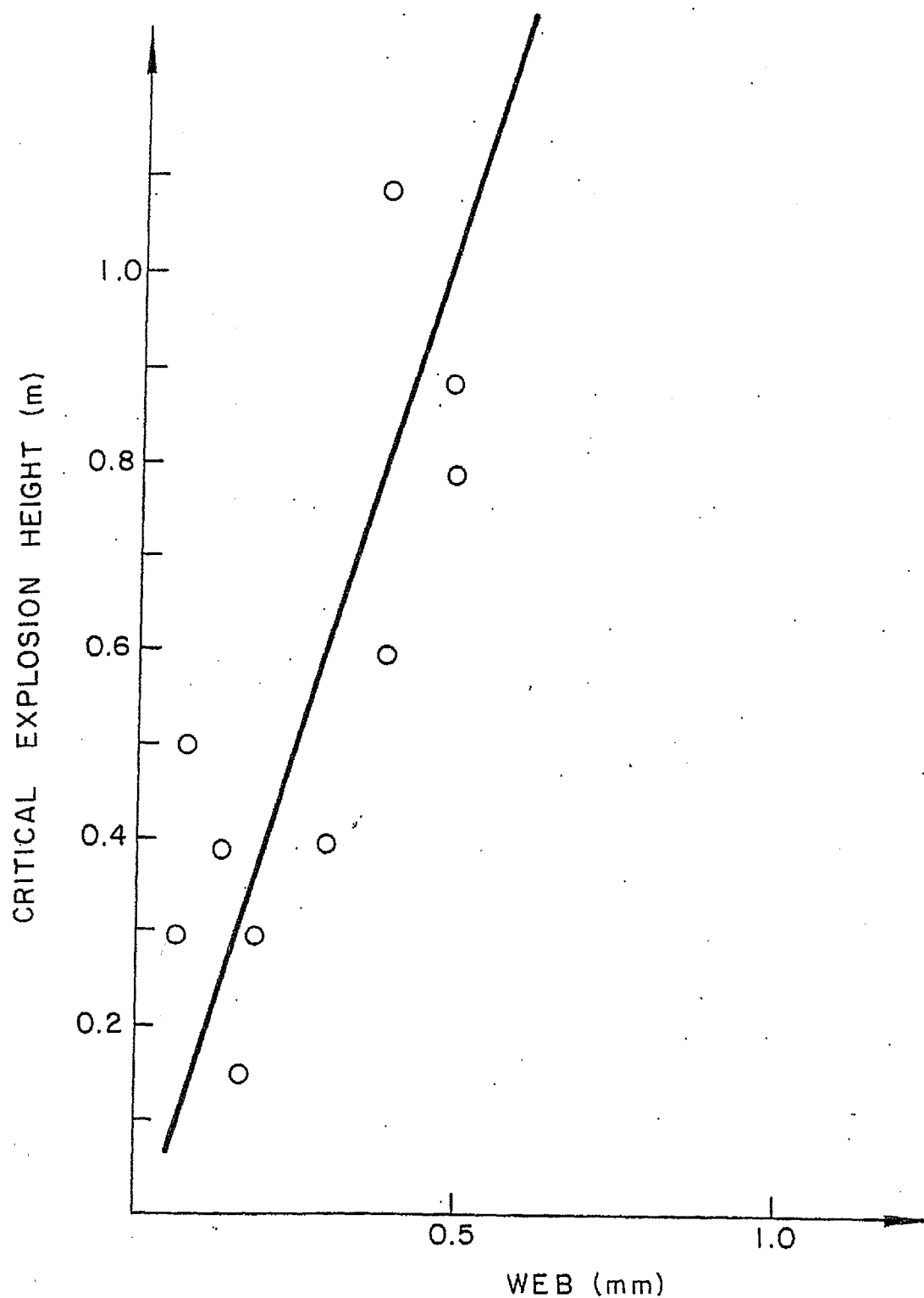
FIGURE 3: CRITICAL EXPLOSION HEIGHT AS A FUNCTION OF WEB
(200mm tube) (B type powders). [2]

The results, plotted in Figure 4 show clearly that the Critical Explosion Height decreases with
increasing heat of combustion of the propellant.

4.6 The "R Function" - Combined Effect of Web, Heat of Combustion and Bulk Density

Lucotte found that he could relate the Critical Explosion Height of a propellant to a function
containing its values of heat of combustion, web thickness and bulk density. This function is
defined as:

$$R = \frac{\text{Heat of Combustion (Q) (cal/g)}}{\text{Web (mm) x Bulk Density (kg/m}^3)}$$

The introduction of a bulk density term permits the self confinement of the propellant to be
partially taken into account. Figure 5 relates CEH with R. The function "R" probably would
be considered as a pseudo vivacity.

Various propellants were evaluated including three porous propellants.

4.7 Influence of Temperature.

Limited tests in France have shown that there is little difference in Critical Explosion Height
between a propellant at about 10°C and the same propellant at 50°C or 60°C.

4.8 Influence of the Condition of the Propellant

4.8.1 Influence of "Finish"

Short grain propellant powders are usually finished by tumbling and graphiting. The tumbling
gives a smooth surface for uniform burning. Graphiting coats this surface to minimize the
hygroscopicity of the powder.

Tests in 82.5 mm diameter tubes showed that "finished" propellants had little effect on the
Critical Explosion Height but a major effect on the Critical Detonation Height, Table 3. This
is for a single base non-porous powder.
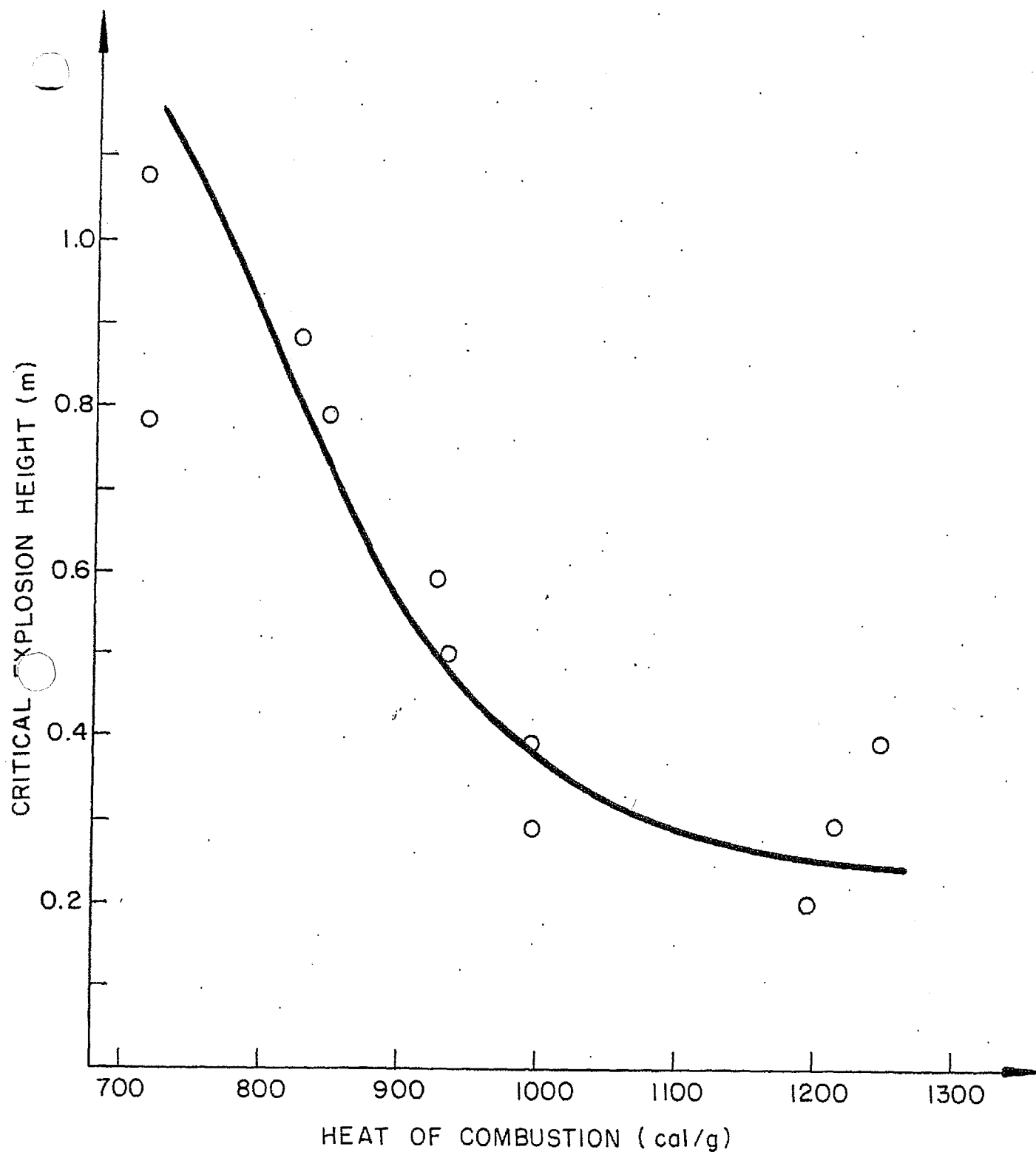
FIGURE 4 : CRITICAL EXPLOSION HEIGHT AS A FUNCTION OF HEAT OF
COMBUSTION. (200mm tube). [2]
Note: All Propellants Had Similar Web Sizes.

MREL

$$R = \frac{Q \;(cal/g)}{WEB \;(mm) \times BULK \;DENSITY \;(kg/m^3)}$$
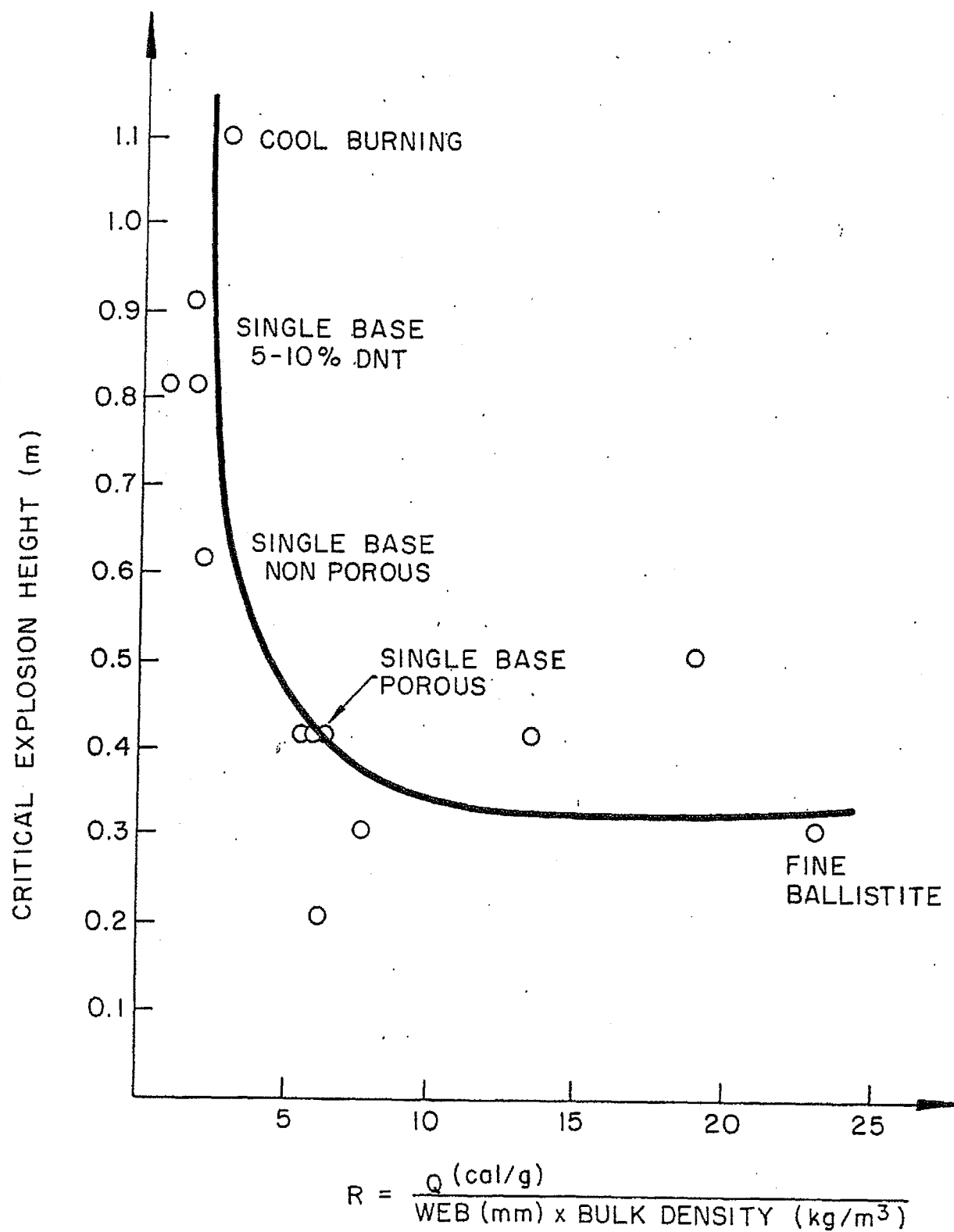
FIGURE 5: CRITICAL EXPLOSION HEIGHT VERSUS R.
(200mm tube).[2]

| | CRITICAL HEIGHT (m) IN 82.5 TUBE | |
	EXPLOSION	DETONATION
Before Finishing and Graphiting	0.15 - 0.25 m	0.25 - 0.50 m
Finished	0.15 - 0.25	> 0.98

TABLE 3: COMPARISON OF CRITICAL HEIGHT FOR FINISHED AND
         NON- FINISHED PROPELLANT

5.0 LARGE SCALE STUDIES OF CRITICAL HEIGHT

The open tube tests described in previous sections are not usually indicative of most of the conditions pertaining to manufacture, storage and transport of propellants. The quantities of propellant tested in 82.5 mm I.D. open tubes seldom exceed 5 kg and quantities tested in the 200 mm ID open tubes seldom exceed 50 kg.

These tests are very valuable in establishing the influence of various parameters on the CEH and CDH and in comparing the potential hazards of different propellants. However they do not yield values of critical height which can be used with confidence to establish, for example, a safe height of propellant in a drying box or safe dimensions for storage or transport containers. For such purposes larger scale tests in simulated or actual containers, hoppers and drying boxes must still be conducted.

French tests on a large scale with two different Ballistites in casks and in boxes are reproduced in Table 4. The height of powder required to produce an explosion was found to be very much greater than that found in the open tube tests. That is, the open tube tests yield conservative results compared to "field" tests in large containers. Construction and dimensions of containers were not noted in Lucotte's paper. However information from a visit in March 1988 was that these and later tests involved 300-500 kg of powder.

6.0 CONCLUSION

Although the work by Lucotte and by Goliger and Lucotte discussed in this present review was done in the period 1976 to 1979 it remains fully relevant to propellant detonation problems. The closed and open tube tests are the principal small scale tests used in France to study new propellants. Since 1979 France has carried out a considerable number of large scale tests directly applicable to particular manufacturing, storage and transport conditions.

As a result of both the small scale (open tube) tests and large scale tests steps have been taken to reduce hazards in all activities involving propellants. Loading hoppers now have light walls

POWDER	OPEN TUBE TEST				LARGE SCALE TESTS IN PACKAGES			
	82.5mm		200mm		TYPE OF PACKAGE	NATURE OF IGNITION "ATTACK"	APPROX HEIGHT OF POWDER	RESULT
	CEH	CDH	CEH	CDH				
	(m)	(m)	(m)	(m)			(m)	
Ballistite	N.A.		0.2-0.3	0.2-0.3	Wooden Barrel	Exterior Ignition with Fuze	0.55	Combustion
					Box Mle 27 Without Cover	Exterior Fire	0.64	Combustion
					Box Mle 27 With Cover	Exterior Fire	0.64	Combustion
					Box Mle 27 With Cover	Interior Hot Wire	0.64	Explosion
					Box Mle 27 PN With Cover	Interior Hot Wire	0.40	Explosion
Ballistite	0.10-0.15	0.15-0.25	0.3-0.4	0.3-0.4	Wooden Barrel	Exterior Ignition With Fuze	0.55	Combustion

NOTE: DETAILS OF PACKAGE SIZE AND CONSTRUCTION NOT SUPPLIED WEIGHT OF POWDER NOT GIVEN

TABLE 4: COMPARISON OF OPEN TUBE TESTS AND LARGE SCALE TESTS

to reduce confinement. Heights of propellant beds in hoppers, drying boxes and storage and transport containers are now well below the Critical Explosion Height for the particular propellant. Wherever possible smaller quantities of propellant are moved continuously or more frequently instead of moving larger quantities at one time. Large scale field tests have been performed to ensure that the explosion or detonation of propellants in storage locations is not transmitted to adjacent locations.

REFERENCES

1) Goliger J and Lucotte J-P (SNPE), "Detonabilité des Poudres" Sciences et Techniques de l'Armement 55, 1, 1981.

2) Lucotte J-P (SNPE) "Hauteurs Critiques d'Explosion et de Detonation". Paper presented at ICT Conference, Karlsruhe, 1979.

APPENDIX C

FEDERAL REPUBLIC OF GERMANY

STUDIES OF PROPELLANTS - BURNING TO DETONATION

FEDERAL REPUBLIC OF GERMANY

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

Germany has had no accidents in which propellants are believed to have burned to detonation.

Although a considerable amount of work is believed to have been conducted on the deflagration to detonation problem we were able to obtain only a small amount of information on the DDT.

One test used extensively in German studies is a small scale open tube test of 50 cm inside diameter, 3 mm wall and 350 mm long. The propellant charge is ignited at the bottom by a small gasless squib. Fragmentation of the tube is taken as indicating explosion or detonation.

In large scale tests, similar to U.N. Test Series 6, German studies have found that the confinement provided by the packaging container can influence whether a propellant behaves as HD 1.1 or HD 1.3.

Quantities of propellants at all stages of manufacture and loading are kept as small as possible. Air drying of propellants is regarded as a major hazard.

1.0 ACCIDENTS

Germany has had no accidents in which propellants are believed to have burned to detonation in process, transport or storage.

One accident occurred in which a propellant is believed to have exploded, but not detonated, in a gun. The pressure was about 15 kbar. The accident was attributed to brittle fracture of the propellant at the firing temperature of -40°C combined with possible improper ignition which resulted in a standing wave in the chamber of the gun.

2.0 SMALL SCALE STUDIES AND TESTS

The one small scale test used by Germany is a steel tube 350 mm long, inside diameter 50 cm, wall thickness 3 mm. The tube is sealed at the bottom, open at the top and is filled with propellant at a loose bulk density. The propellant is ignited at 50 mm from the bottom using a small gasless squib ($Pb_3O_4 + Si$). Fragmentation of the tube is taken as indicating detonation or explosion. No fragmentation indicates that only burning took place.

This test is very similar to the open steel tube test used in Finland. It differs from the French open tube test.

3.0 LARGE SCALE TESTS U.N. TESTS - TEST SERIES 6

The FRG uses the Series 6 U.N. tests, in some cases with variations, to determine whether an explosive as packaged for transport should be classified as HD 1.1 or HD 1.3.

It has been found that the method of packaging can determine the hazard division. For example, a propellant in a steel shipping drum might test as HD 1.1, but in a fiberboard drum might test as HD 1.3 and in a heavy fibre case again test as HD 1.1.

For this reason they try to store and transport propellants in the type of container that will cause the packaged material to behave as HD 1.3.

4.0 OTHER LARGE SCALE TESTS

The German test agency, BAM, has developed a number of large scale tests in addition to the U.N. Test Series 6. However they were not prepared to divulge these tests at the time of our visit.

5.0 EFFECT OF COMPOSITION, DENSITY, WEB SIZE

BAM regards the information it has on the effects of composition, density and web size of propellants on their hazard division characterization as proprietory and thus declined to discuss this. However they did provide information that:

a) 1/3 of civilian propellants are HD 1.3   2/3 of civilian propellants are HD 1.1

b) almost all military propellants are HD 1.3

c) porous single base powders are usually HD 1.1 in the finished state but before the removal of KNO_3 are usually HD 1.3

6.0 PRECAUTIONS

Quantities of propellants at all stages are kept as small as possible and operations are separated from each other by very conservative safety distances. Air drying of propellants is regarded as a major hazard. It has also been found that close to a propellant or pyrotechnic fire thermal radiation can be a major hazard and can cause injury to personnel or ignition of other materials. Safety glass does not effectively screen people from thermal radiation and should therefore not be used where this is likely to be a hazard.

APPENDIX D

NETHERLANDS

STUDIES OF PROPELLANTS - BURNING TO DETONATION

NETHERLANDS

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

A major accident occurred at the Muiden Chemie B.V. propellant factory near Amsterdam in 1972 during the manufacture of porous propellants. Even before this accident, a special Government Commission had been set up to study the possible risks involved in accidents at this factory. After the 1972 accident a crash program was set up. This crash program, together with the studies of the Commission, resulted in major changes to the factory in terms of process procedures and quantity-distance values for propellants.

Following the crash program, continuing studies by the Company and by the Government laboratory (TNO) have resulted in a methodology for assessing the deflagration-to-detonation potential of propellants, not only in the finished state but also at various stages of manufacture. The main criteria used in estimating this potential are: composition, web size, vivacity. Other factors are also considered, especially solvent content. From these parameters a realistic estimate of critical explosion height can be made. For any significantly new propellant actual large scale tests to firmly establish this height are also performed.

The Netherlands methodology is one which we recommend be adopted in Canada.

1.0 ACCIDENTS

A major accident occurred at the Muiden Chemie Propellant Factory near Amsterdam in 1972 during the manufacture of porous propellants[1]. The most likely cause was considered to be an electrostatic discharge in propellant dust during a drying operation. More than 2 tons of porous single base propellant were involved in the explosion, although not all of this may have detonated or exploded.

A second fatal accident occurred in Muiden Chemie in May 1983. This accident happened when workmen were repacking dried, tubular porous propellant in long igniter stick form from

drying containers into fibre drums. The investigation found that the igniter sticks were strongly charged electrostatically during the drying process. The employees repacking the sticks were also electrostatically charged. It was concluded that a combination of a spark discharge from one of the employees and deposits of dust in a mushroom mixer in the workroom was the cause of the explosion. About 240 kg of propellant exploded; three employees were killed.

2.0 TESTS TO STUDY THE TRANSITION - BURNING TO DETONATION

Following the first accident a "crash" program was initiated to study the deflagration-to-explosion-to-detonation properties of propellants[1]. The tests were "field tests" using large quantities of propellants in containers and boxes closely simulating those used in production, transport and storage of propellants. These tests yielded results which were almost immediately used in propellant operations. However, because of both cost and difficulty in carrying out large scale tests, smaller scale "laboratory" tests were also performed. Both types of tests are described below. Testing was conducted cooperatively by the Government Laboratory (TNO) and by the firm Muiden Chemie.

After the "crash" tests the Company continued with a program to develop more comprehensive information on the deflagration to detonation phenomena.

Following the 1983 accident, TNO again became directly involved in a specific accident study. This was particularly focused on such tests as impact, friction and electrostatic sensitivity. Results of electrostatic sensitivity tests are given later in this review report.

3.0 SMALL SCALE OPEN TUBE TEST

This test is conducted in a steel tube having the following dimensions:

length   - 1.18 m

inside diameter   - 30 and 50 mm

wall thickness   - 10 mm

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Its wall thickness and hence, confinement, is considerably greater than the tubes used in similar tests in Finland and Germany. The tube is closed at one end with a screwed cap that has a small hole for the insertion of an igniter which consists of an electric squib plus 2 g of pyrotechnic mixture. A continuous reading wire probe is inserted through the open end along the axis to about 10 cm above the point of ignition at the bottom of the tube. In the test, the tube is filled with propellant and ignited. The probe gives a measure of the distance travelled by the reaction front versus time, from which velocity can be calculated. By replacing the igniter by a small booster charge of plastic explosive and a detonator, the velocity of detonation of the propellant under the same diameter and confinement conditions can be measured. Table 1 gives the results of three typical small scale tests reported by TNO[1]. The three danger classes noted are described below.

4.0 DANGER CLASSES

The Netherlands Government distinguishes a total of 8 danger classes of explosives and ammunition. Of these, propellants form 3 classes.

Danger Class 1

Products falling into this danger class are fire-dangerous. Under the conditions of manufacture of such propellants a transition from burning-to-explosion is not to be expected. The consequences of a fire remain limited and only lead to fire damage in and at the room where the fire took place. Flying fragments are not to be expected at any great distance. If a quantity of this class of material is surrounded by fire, this will not lead to a mass-explosion. This danger class equates to U.N. Hazard Division 1.3.

Danger Class 2

The products falling into this danger class are mass-fire-dangerous. They can cause an explosion, however, without the risk of a detonation. Usually no dangerous flying fragments are formed or pressures are generated which cause structural damage in the surroundings. Burning flying fragments and burning packaging materials can fly about in the case of an explosion. Materials in this danger class are treated in the Netherlands as equivalent to U.N. Hazard Division 1.3 for the determination of safety distances, both interior and exterior.

DANGER CLASS	VELOCITY m/s	
	FLAME IGNITION	BOOSTER INITIATION
1	max 600 m/s	6000 m/s
2	1300 m/s	4000 m/s
5	3200 m/s	4000 m/s

**TABLE 1: VELOCITY RESULTS FOR FLAME AND BOOSTER INITIATION FOR A
TYPICAL POROUS PROPELLANT .**

Danger Class 5

The products falling into this danger class can burn to <u>detonation</u>. This will result in serious structural damage, which is more serious if the quantity of detonating material involved is large. As the quantity of detonating material increases, the effect will be spread further in the surroundings. The pressure- wave and the flame are the most important dangers threatening the surroundings. This danger class equates to U.N. Hazard Division 1.1 but is also a fire hazard. In the Netherlands safety distances for HD 1.1 are more conservative than those recommended in the NATO AC/258 Q-D tables.

5.0 CRITICAL EXPLOSION AND DETONATION HEIGHTS

In addition to its use in classifying a propellant, the open tube test provides information on the height of bed at which transition to explosion or detonation may occur. These are, respectively, called Critical Explosion Height (CEH) and Critical Detonation Height (CDH).

It is obvious that Danger Class 1 materials under the conditions of the open tube test, have a CEH greater than the length of the tube, which is 1.18 m long. In reported results, Danger Class 2 propellants have critical explosion heights less than the length of the tube but do not detonate. Danger class 5 propellants achieve transition to detonation well within the length of the open tube. Critical heights are shown by the point at which the reaction rate (ie., velocity) becomes constant. Critical heights as found in the small scale tests may be different than critical heights found in large scale tests where confinement is different.

6.0 LARGE SCALE STUDIES ("FIELD TESTS")

Three types of large scale tests are used, simulating conditions pertaining to actual practice in manufacture, transport and storage. These are: tests in cylindrical aluminum containers; tests in oblong aluminum containers; tests in fibre-board drums.

These tests were conducted as part of the "crash" program and are still used.

6.1 Tests in Cylindrical Aluminum Containers

These containers have the following dimensions:

inside diameter   - 80 cm

wall thickness   - 3 mm

height of container   - 90 cm

- In the test the propellant is loaded to a height of about 75 cm. (propellant weight 350 kg).

- Ignition is by a squib surrounded by 2 g of a pyrotechnic mixture located at a depth of about 25 cm in the propellant.

- Blast is measured by piezo-electric pressure transducers placed 1 m above ground level and at distances of 25, 50, 75 and 100 m from the container.

Some results of tests are shown in Table 2.

In the test of the single perforated single base propellant compacted by vibration the compaction of the propellant in effect increased the confinement to such a degree that a small quantity of the charge appears to have exploded.

It should be noted that the smallest web for the non-porous propellants was 0.48 mm (0.019 inch). Studies in other countries have shown that non-porous propellants of this web and larger have little tendency to burn to the point of explosion. This and other large scale tests may be varied by increasing or decreasing the height of the propellant bed or changing the point of ignition.

6.2 Tests in Oblong Aluminum Containers

The dimensions of these containers are:

length   - 1.25 m

width   - 0.66 m

height   - 0.71 m

wall thickness   - 3.0 mm

TYPE OF PROPELLANT	WEB SIZE mm	inch	BEHAVIOUR	TNT EQUIV.	REMARKS
multiperforated single base	1.3	0.052	burning	NA	
single perforated single base	0.8	0.032	burning	NA	
single perforated single base	0.6	0.024	burning partial explosion	NA 5 - 15 percent	a) loose filled b) compacted
single perforated double base	0.48	0.019	burning	NA	9% NG
porous NC			detonation	20 - 60 percent	

TABLE 2: SOME RESULTS OF TESTS IN CYLINDRICAL ALUMINUM
CONTAINERS

Their capacity is 350 kg.

6.3 Tests in Fibre-board Drums

The dimensions of these are:

   diameter - 0.36 m

   height   - 0.60 m

Their capacity is 25 kg.

7.0 ELECTRIC SPARK TESTS

These tests were carried out as a result of the 1983 accident involving centre-core igniter sticks
made of porous propellant. The results are summarized in Table 3 with results from a
non-porous propellant and a short "T" shaped porous propellant. All propellants were ground
to produce powders of different fineness.

8.0 TNT EQUIVALENCE OF PROPELLANTS

When a quantity of propellant is deliberately detonated by means of an explosive booster, it
will produce an overpressure shock pulse and an impulse in the same way as any explosive
material. As with other explosives, the overpressure and impulse may be greater or less than
would be the case with the same quantity of TNT. By comparison of shock or impulse values
the propellant can be assigned an equivalence value in terms of percentage of output obtained
from TNT.

However, when a propellant is ignited by a flame and burns to the point of detonation, only a
portion of the propellant will detonate and generate a shock wave. The TNT equivalence of
the propellant in such a case will depend on a number of factors and the same propellant under
different conditions may have different TNT equivalence values.

PROPELLANT	PARTICLE SIZE DIAMETER (mm)			SPARK (J)
centre core igniter sticks	0 0.5	< <	0.5 1.0	0.6 1.0
non-porous propellant	0 0.5	< <	0.5 1.0	--- 0.7
porous propellant T 70	0 0.06 0.1 0.2 0.5	< < < < <	0.06 0.1 0.2 0.5 1.0	0.06 0.10 0.16 0.25 0.50

For comparison:

Sulphurless mealed gunpowder ignites at 0.45J. PETN and B. HMX have no ignitions at 0.45J (U.K. tests using different apparatus)

TABLE 3: SENSITIVITY OF PROPELLANTS TO SPARK. (MINIMUM SPARK ENERGY FOR IGNITION)

The TNT equivalence of a propellant under a specific condition may be expressed as either a percentage of TNT or as the number of kilograms of the propellant which give the same blast as 1 kg of TNT.

9.0 VIVACITY

The vivacity, A, of a propellant is its rate of change of pressure with pressure.

$$A = \frac{\frac{\Delta p}{\Delta t}}{P \times P_{max}} \quad bar^{-1} \, sec^{-1}$$

The closed vessel used in the Netherlands was not described but is probably the standard NATO type having a volume of 700 mL and a maximum rated pressure of about 248 MPa.

In Canada, this standard is followed. A suitable design is the RARDE Model CV21. Ignition of the propellant powder is usually with a small quantity of black powder and an electrical ignition wire attached to electrodes in the top plug of the closed vessel.

The vivacity of a propellant will depend on such factors as composition, density, web size. The vivacity therefore encompasses a number of the parameters which are known to affect the deflagration-to-detonation transition and can be used to assist in predicting the danger of such an event occurring with a particular propellant.

From limited data available from the Netherlands tests, the Critical Height for Detonation appears to decrease linearly with increasing vivacity.

Methods and equipment for measurement of vivacity are described in References 4 to 7 inclusive.

10.0 DANGER CLASSES AT STAGES IN MANUFACTURE

Netherlands large scale tests have established that as a propellant proceeds through the various stages of manufacture its hazard class may change.

10.1 In the Paste Mixing/Solvent Gelatinizing Process

(a) single based powders will be fire dangerous only, ie. Danger Class 1, by virtue of the phlegmatizing effect of the solvents.

(b) powders containing more than 20% nitroglycerine may fall into Danger Class 2 at this stage.

10.2 In the Solvent Drying Stage

Some powders will change from Danger Class 1 to Danger Class 2 at the point where the remaining solvent is decreased to 12%. Porous powders containing less than 30 weight % of potassium nitrate reach the Danger Class 2 level at this stage. At less than 12% solvent some propellants will be Danger Class 5.

10.3 Pressing Stage

Porous powders, in process, containing more than 30% of potassium nitrate reach Danger Class level 2 at the pressing stage.

At the stage where a powder reaches the Danger Class 2 stage, it is very important to make sure that the charge depth in containers is always less than the Critical Explosion Height. This is particularly important if the powder has the potential of behaving as Danger Class 5. If it is not possible to keep the depth of propellant below the Critical Explosion Height and it has the potential for Danger Class 5, than precautions appropriate to that class should be observed. For Danger Class 5, quantity-distance tables for U.N. Hazard Division 1.1 are appropriate. The TNT equivalence may, in this instance, be taken into account in determining Q-D values.

11.0 PROPELLANT CATEGORIZATION FOR MANUFACTURE

The Netherlands propellant manufacturing company, Muiden Chemie B.V., categorizes propellants into 5 groups for the purpose of establishing danger classes at the factory level. The characteristics and parameters used in identifying the danger class are: composition, number of perforations, vivacity, web size, Critical Detonation Height (CDH).

The propellant groups are:

Group I : Single-perforated, single-base powders with a nitrocellulose percentage ≤ 98% and a web ≥ 0.19 mm.

Group II : Multi-perforated, single-base powders with a nitrocellulose percentage ≤ 98% and web ≥ 0.19 mm.

Group III : Double-base powders with web ≥ 0.19 mm.

Group IV : Triple-base powders with web ≥ 0.19 mm.

Powders which cannot be divided into the above groups form the remaining group:

Group V : Single, double and triple-base powders with web < 0.19 mm and/or a nitrocellulose percentage > 98%.

The roles played by vivacity, web size, composition and form (single or multiple perforated, porous) in determining safe conditions at each stage in the production of propellants are shown in Figures 1 to 5 inclusive. An attempt has been made in Figure 6 to summarize a part of the information contained in Figures 1 to 5. Figure 6 oversimplifies the critical height versus vivacity relationship but at least indicates the essential linearity of that relationship and provides a quick estimate of levels for various propellants. The importance of vivacity and web size in relation to the danger class cannot be overemphasized.

It should be noted that the Netherlands system of hazard classification of propellants was developed from a system used by the U.S. Department of Defense.

11.1 Applicability of the Muiden Chemie B.V. Criteria

The criteria used by Muiden Chemie for designating the danger inherent in factory operations in terms of propellant composition, web, vivacity and other parameters should be directly applicable to many propellant manufacturing, transport and storage situations in Canada because of the similarity in types of propellants. Therefore, consideration should be given to using Figures 1 to 5 in evaluating the safety of Canadian operations and procedures.

DANGER INDICATION AT FACTORY

(A) Web ≥ 0.89 mm — — — — — — — — — — — (a) not surface treated
(b) surface treated

(A) critical detonation height : > 140 cm.
detonation danger : none
finished product : danger class 2.

(B) critical detonation height : > 140 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
finished product : danger class 2.

(I) single-base single perforated powder with nitrocellulose percentage ≤ 98%

(1) Vivacity ≤ 30.10⁻²bar⁻¹sec⁻¹
Obligatory reduction of charge depth in air drying container to max. 110 cm.

(a) not surface treated
(A) critical detonation height : > 110 cm.
detonation danger : none
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.

(b) surface treated
(B) critical detonation height : > 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.

(2) Vivacity > 30; but < 45 10⁻²bar⁻¹sec⁻¹

(a) not surface treated
(A) critical detonation height : 65 - 110 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.

(b) surface treated
(B) critical detonation height : 65 - 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.

(B) Web 0.19 - 0.89 mm

(3) Vivacity ≥ 45.10⁻²bar⁻¹sec⁻¹
Obligatory reduction of charge depth in aluminum 300 kg container to max. 40 cm.

(a) not surface treated
(A) critical detonation height : 45 - 65 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

(b) surface treated
(B) critical detonation height : 45 - 65 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

FIGURE 1: GROUP I - SINGLE-BASE, SINGLE PERFORATED POWDER WITH NITROCELLULOSE PERCENTAGE ≤ 98%.

DANGER INDICATION AT FACTORY

(A) Web ≥ 0.48 mm — — — — — — — — — — — — — (a) not surface treated

(A) critical detonation height : > 140 cm.
detonation danger : none
finished product : danger class 2.

(b) surface treated

(B) critical detonation height : > 140 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
finished product : danger class 2.

(II) single-base multi-perforated powder with a nitrocellulose percentage ≤ 98%

(1) Vivacity ≤ 30.10⁻²bar⁻¹sec⁻¹
Obligatory reduction of charge depth in air drying container to max. 110 cm.

(a) not surface treated

(A) critical detonation height : > 110 cm.
detonation danger : none
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.

(b) surface treated

(B) critical detonation height : > 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.

(2) Vivacity > 30; but < 45 10⁻²bar⁻¹ sec⁻¹

(a) not surface treated

(A) critical detonation height : 65 - 110 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.

(B) Web 0.19 - 0.48 mm

(b) surface treated

(B) critical detonation height : 65 - 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.

(3) Vivacity ≥ 45.10⁻²bar⁻¹sec⁻¹
Obligatory reduction of charge depth in aluminum 300 kg container to max. 40 cm.

(a) not surface treated

(A) critical detonation height : 45 - 65 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

(b) surface treated

(B) critical detonation height : 45 - 65 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

FIGURE 2:   GROUP II - SINGLE-BASE, MULTI-PERFORATED POWDER WITH NITROCELLULOSE
PERCENTAGE ≤ 98%.

(1) Vivacity ≤ 30.10⁻² bar⁻¹ sec⁻¹
Obligatory reduction of
charge depth in air drying
container to max. 110 cm.

(a) not surface treated

(A) critical detonation height : > 110 cm.
detonation danger : during filling of
material in mixing trough
As a result of obligatory reduction in air dryi
not detonable
finished product : danger class 2.

(b) surface treated

(B) critical detonation height : > 110 cm.
detonation danger : during filling of
material in mixing trough; in barrels as a resu
in. class 5)
As a result of obligatory reduction in air dryi
not detonable
finished product : danger class 2.

(A') nitroglycerine content < 20%

(2) Vivacity > 30; but < 45 10⁻² bar⁻¹ sec⁻¹

(a) not surface treated

(A) critical detonation height : 65 – 110 cm.
detonation danger : during filling of
material in mixing trough; in air drying contai
of surpassing of critical detonation height (da
finished product : danger class 2.

(b) surface treated

(B) critical detonation height : 65 – 110 cm.
detonation danger : during filling of
material in mixing trough; in barrels as a resu
in and in air drying container as a result of w
critical detonation height (danger class 5).
finished product : danger class 2.

(A) containing nitroglycerine

(3) Vivacity ≥ 45.10⁻² bar⁻¹ sec⁻¹
Obligatory reduction of charge
depth in aluminum 300 kg
container to max. 45 cm.

(a) not surface treated

(A) critical detonation height : 45 – 65 cm.
detonation danger : during filling of
material in mixing trough; in air drying contai
of surpassing of critical detonation height (da
As a result of obligatory reduction in aluminum
container not detonable.
finished product : danger class 2.

(b) surface treated

(B) critical detonation height : 45 – 65 cm.
detonation danger : during filling of
material in mixing trough; in barrels as a resu
in and in air drying container as a result of w
critical detonation height (danger class 5).
As a result of obligatory reduction in aluminum
container not detonable.
finished product : danger class 2.

(III) Double-base powders
with web ≥ 0.19 mm

(A') nitroglycerine content 20-30%

(p)

(p) if semi manu-
factured
contains > 25%
solvent

(P) Not detonable

(q)

(q) finished
product and
semi-manu-
factured
containing
< 25% solvent

(Q) It is stated that the finished product is detona

(B) containing nitroguanidine Nitroguanidine content < 35%

critical detonation height : see division group
detonation danger : see division group
also the addition
nitroguanidine in
trough (danger cla
finished product : danger class 2.

FIGURE 3: GROUP III – DOUBLE-BASE POWDER WITH WEB SIZE ≥ 0.19 mm.

DANGER INDICATION AT FACTORY

(IV) Triple-base powder with web ≥ 0.19 mm

(A) nitroglycerine content < 20% and also nitroguanidine content < 45%

(1) Vivacity ≤ $30.10^{-2}bar^{-1}sec^{-1}$
Obligatory reduction of charge depth in air drying container to max. 110 cm.

(a) not surface treated

(A) critical detonation height : > 110 cm.
detonation danger : during fillin
material in mixing trough
As a result of obligatory reduction in air
not detonable
finished product : danger class

(b) surface treated

(B) critical detonation height : > 110 cm.
detonation danger : during fillin
material in mixing trough; in barrels as a
in. class 5)
As a result of obligatory reduction in air
not detonable
finished product : danger class

(2) Vivacity > 30; but < 45 $10^{-2}bar^{-1}sec^{-1}$

(a) not surface treated

(A) critical detonation height : 65 - 110 cm.
detonation danger : during fillin
material in mixing trough; in air drying c
of surpassing of critical detonation heigh
finished product : danger class

(b) surface treated

(B) critical detonation height : 65 - 110 cm.
detonation danger : during fillin
material in mixing trough; in barrels as a
in and in air drying container as a result
critical detonation height (danger class 5
finished product : danger class

(3) Vivacity ≥ $45.10^{-2}bar^{-1}sec^{-1}$
Obligatory reduction of charge depth in aluminum 300 kg container to max. 40 cm.

(a) not surface treated

(A) critical detonation height : 45 - 65 cm.
detonation danger : during fillin
material in mixing trough; in air drying c
of surpassing of critical detonation heigh
As a result of obligatory reduction in alu
container not detonable.
finished product : danger class

(b) surface treated

(B) critical detonation height : 45 - 65 cm.
detonation danger : during fillin
material in mixing trough; in barrels as a
in and in air drying container as a result
critical detonation height (danger class 5
As a result of obligatory reduction in alu
container not detonable.
finished product : danger class

(B) nitroglycerine content 20-30% and/or nitroguanidine content ≥ 45%

(P) — — — — — — — — —

(p) if semi manu-factured contains > 25% solvent

(P) Not Detonable

(Q) — — — — — — — — —

(q) finished product and semi-manu-factured containing < 25% solvent

(Q) It is stated that the finished product is

FIGURE 4: GROUP IV - TRIPLE-BASE POWDER WITH WEB SIZE ≥ 0.19 mm.

DANGER INDICATION AT FACTORY

(V) Single, double and triple-base powders with web < 0.19 mm and/or N.C. content > 98%

(A) Web < 0.19 mm

(A') non-porous powder

(1) Vivacity < 45 x 10^{-2}bar^{-1}sec^{-1}
   (A) If semi-manufacture contains ≥ 12% solvent
   (B) If semi-manufacture and the finished product contains < 12% solvent

(2) Vivacity ≥ 45 x 10^{-2}bar^{-1}sec^{-1} Obligatory reduction of charge depth in aluminum container to max. 40 cm.
   (A) If semi-manufacture contains ≥ 12% solvent
   (B) If semi-manufacture and the finished product contains < 12% solvent

(A") porous powder
   (A) Before potassium nitrate has been extracted
   (B) After potassium nitrate has been extracted

(B) Nitrocellulose content > 98%
   (A) If semi-manufacture contains ≥ 25% solvent
   (B) If semi-manufacture and end product contains < 25% solvent

FIGURE 5: GROUP V - SINGLE, DOUBLE AND TRIPLE-BASE POWDERS WITH WEB SIZE < 0.19 mm AND/OR A NITROCELLULOSE CONTENT > 98%.

MREL

FIGURE 6 : CRITICAL HEIGHT VERSUS VIVACITY

For: Single Base, Single Perf.   Web 0.19 - 0.89
      Single Base, Multi Perf.   Web 0.19 - 0.48
      Double Base   Web ≥ 0.19
      Triple Base   Web ≥ 0.19

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REFERENCES

1.   Cruysberg, Pasman and Groothuizen: Technical Laboratory, TNO The Netherlands "Propellant Detonation Risk Testing".

2.   Muiden Chemie B.V., "The Danger Classes of Propellants", (This appears to be a paper prepared by the Company for private distribution).

3. U.S. Department of Defense, "Contractors Safety Manual for Ammunition and Explosives".

4. NATO STANAG 4115

5. U.S. MIL-STD-286A

6. DND Proof and Experimental Test Establishment Technical Memo 2/68.

7. DREV Memorandum 2708/84.

APPENDIX E

SWITZERLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SWITZERLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

An accident occurred at the Swiss Federal Propellant Plant at Wimmis in December 1978 in a building used for blending and storing propellants. About 100 tonnes of propellant burned very rapidly but did not explode. There were no deaths or injuries. As a result of this the Swiss carried out a major study of their propellant manufacturing and loading operations and, in particular, the potential of three different propellants to burn to detonation when contained in three different types of containers. The containers were of types used for storage and transport of propellants.

The three propellants were:

   a) single base, porous

   b) flake - similar to Ballistite, web .0076 in. (0.19mm)

   c) single base, single perforated, non-porous, web 0.013 in. (0.325 mm)

The large scale tests are important in that they show how critical explosion and critical detonation heights of propellant vary with size and type of container and with propellant web size. However, since only three very different propellants were studied it is not possible to estimate critical explosion or detonation heights for other propellant compositions, web sizes or container sizes and types. Swiss workers have also reported on development and tests of a new building concept for propellant storage.

1.0 INTRODUCTORY NOTE

Switzerland was not one of the countries visited as part of this study. However, we have found that a considerable amount of work has been performed by the Swiss Federal Propellant plant at Wimmis to study the transition from deflagration to detonation of propellants.

The Swiss work is of particular importance because it studies, for three different propellants, the influence of different sizes and types of containers, confinement, critical heights of propellant and the location and type of ignition on the deflagration to detonation behaviour of the propellants. It reports results of large scale types of tests not sufficiently well reported by other countries.

2.0 ACCIDENTS

Swiss studies have been influenced by two accidents. The first of these was not one which occurred in Switzerland but in a Finnish propellant loading plant at Lapua in 1976[1], the design of which was similar to that of a Swiss small arms loading plant. The second accident was one which occurred in the Swiss Federal Propellant Plant at Wimmis in December 1978[2]. In this accident about 100 tons of propellant, in a building used for mixing (blending) and storing of propellants, burned within a few seconds but did not detonate. The building was destroyed but no one was injured.

As a result of the accident in Finland the Swiss conducted a Hazard Analysis study of their own loading plant. The study concluded that it would not be necessary to go to the extent to which the Finns had gone in redesigning the loading plant and processes provided that steps were taken to design their propellant drums and hoppers to prevent propellants burning to detonation in them if accidentally ignited.

To obtain the information needed to design safe drums and hoppers for the propellant loading facility and also to design containers for safe transport and storage, a fairly comprehensive series of large scale tests was performed.

3.0 LARGE SCALE TESTS

The tests reported here are summaries of the tests reported by R. Frauenfelder of the Swiss Federal Propellant Plant (2). His report should be consulted for more detailed results. Three types of propellant were used in three tests. Their properties are given in Table 1. Three basic types of containers, with variations in confinement, were used. These are described in Table 2.

3.1 Tests of Propellants in Container Type 1a

In these tests the three types of propellant were tested at different temperatures and heights of bed to determine a critical height of explosion or detonation. The point of ignition in all tests shown in Table 3 was 5cm above the bottom of the container. Explosion and detonation were determined by the size of the crater, fragmentation of the container and by the noise and flash which occurred.

For the Type 1a container the temperature of the propellant and the height of the propellant bed clearly influence the conditions which will result in a transition from deflagration to detonation. Web size and porosity are relevant to this transition.

3.2 Tests of Propellant Type 3 in Cylindrical Steel Containers Types 1b to 1e.

Containers 1b to 1e all provide less confinement than container 1a because of their lower strength bottom closures. This series of tests was carried out to obtain data on the effect of confinement strength on critical height. Results are shown in Table 4 reproduced from Frauenfelder.[2]

Bottom confinement strength of the containers decreases from containers 1b to 1e. Too few tests were done for firm conclusions to be drawn. However, it appears, by comparison of results shown in Table 3 with results in Table 4, that the critical propellant height for containers 1a and 1b are about the same.

There is enough difference in bottom confinement between container 1c and container 1d that detonation occurs in container 1c at a height of bed of 100 cm but does not occur at the same

TYPE	COMPOSITION		HEAT OF EXPLOSION J/g	THICKNESS OR WALL THICKNESS (web) mm (inches	DENSITY g/cm^3	SPECIFIC SURFACE m^2/kg
	NC %	NG %				
Type 1 Porous, single base, single perforated, short tube	96.9	---	3949	0.39 mm (0.0156in)	0.32	48.2 (including pores)
Type 2 Flake	54	42	4884	0.19 mm (0.0076in)	0.71	8.4
Type 3 non porous, single base, single perforated, short tube	96.5	--	3919	0.33 mm (0.0132in)	0.92	5.2

NOTE 1: The Type 3 propellant would appear to be similar to FNH propellants in the 0.012 or .014 web size range. It should be noted that the U.K. considers FNH 014 to be just in hazard division 1.1 .

NOTE 2: The igniters used in all tests were designed to give a purely thermal ignition without the effects of gas shock. Except where specified they were placed 5 cm above the bottom of the container. Each igniter contained 10.4 g of the Type 3 propellant enclosed in wooden cylinders closed at the ends by cardboard discs. Ignition was by an electrically heated wire.

TABLE 1: DESCRIPTION OF PROPELLANTS[2]

CONTAINER	DESCRIPTION
Type 1a	a cylindrical steel container featuring a height of 100 cm, an inside diameter of 30 cm, a wall thickness of 1 cm, without lid, but with a steel base plate of 1 cm welded to the base of the container.
Type 1b	as per (1a) above, the bottom plate being replaced by a steel grate which is fastened to the container with four M 16 screws. A piece of canvas* is placed and pinched between the rim of the container and the grate. The grate mesh measures 30 X 30 mm^2, its ribs 2 X 25 mm^2. The container has four legs welded on its lower part, such that a free space of 115 mm exists between grate and ground.
Type 1c	as per (1b) above, but instead of a grate and canvas, two boards of pine wood, each 12 mm thick being stacked on top of one another.
Type 1d	as per (1c) above, but the base being made of 1 1/2 boards of pine wood.
Type 1e	as per (1c) above, the base consisting of 1 board of pine wood only.
Type 2	rectangular pallet-container, 2 mm corrugated steel plate at the base, 1.5 mm corrugated steel plates at the sides, welded, without lid. Internal dimensions 1197 X 797 X 800 mm^3 high, volume 763 1.
Type 3a	wooden Euro-pallet with wooden side walls made of 30 mm plywood (birch), screwed, without lid. A 5 mm hardboard is nailed upon the pallet floor. Internal dimensions 1140 X 740 X 800 mm^3 high, volume 674 1.
Type 3b	wooden Euro-pallet with wooden side walls made of 19 mm chip board. The pallet floor being covered with a coarse canvas*. Internal dimensions 1162 X 762 X 610 mm^3 high, volume 540 1. This container is suitable for drying out of solvent containing propellants, thanks to its permeable canvas flooring.

NOTE: *   The canvas used with containers Type 1b and 3b is twilled linen having 21 threads/cm of cotton yarn Ne 16/2 raw and 17 threads/cm of flax yarn Ne 12/1 raw.

TABLE 2: DESCRIPTION OF CONTAINERS[2].

PROPELLANT TYPE	PROPELLANT TEMP. (°C)	HEIGHT OF BED (cm)	MASS (kg)	CRATER DIAM. (cm)	CRATER DEPTH (cm)	PHENOMONON B = DEFLAGRATION E = EXPLOSION D = DETONATION
1	10	32.0	7.28	---	---	B
	14	35.5	8.08	100	20	E
	12	40.0	9.10	200	40	D
	14	25.5	5.8	---	---	B
	71	24.5	5.58	100	20	E
	64	30.0	6.83	200	30	E/D
2	14	42	21.1	---	---	B
	14	43	21.6	180	30	D
	14	45	22.6	120	20	D
3	12	46.5	30.4	---	---	B
	10	47.5	31.0	---	---	B
	10	50.0	32.6	200	40	D
	10	50.5	33.0	200	40	D
	9	52.0	34	200	50	D
	61	28.0	18.3	---	---	B
	66	30.0	19.6	200	30	D
	59	39.0	25.5	200	40	D
	57	52.5	34.3	200	40	D

TABLE 3: TEST INVOLVING CONTAINER TYPE 1a[2].

TYPE OF CONTAINER	PROPELLANT TEMP.	HEIGHT OF BED	MASS	HEIGHT OF IGNITER ABOVE FLOOR OF CONTAINER	CRATER DIAM.	CRATER DEPTH	PHENOMENON
	(°C)	(cm)	(kg)	(cm)	(cm)	(cm)	
1b	11	49.5	32.3	5	100	30	D
1c	11	100.0	65.3	5	200	40	D
	11	100.0	65.3	5	200	40	D
1d	11	100.0	65.3	5	---	---	B*
1e	11	51.5	33.6	5	---	---	B*
	11	60.0	39.2	5	---	---	B*
	11	69.0	45.1	5	---	---	B*
	11	41.0	53.6	5	---	---	B*
	11	90.0	58.8	5	---	---	B*
	11	100.0	65.3	5	---	---	B*
	11	100.0	65.3	5	---	---	B*
	11	100.0	65.3	5	---	---	B*
	11	60.0	39.2	30	---	---	B°
	11	60.0	39.2	30	---	---	B°
	11	60.0	39.2	30	---	---	B°
	11	70.0	45.7	35	150	40	D

B = Deflagration; E = Explosion; D = Detonation

° the wooden floor board was intact after deflagration

* the wooden floor board was fractured and forced out after deflagration.

TABLE 4: RESULT: PROPELLANT TYPE 3[2].

height of bed in container 1d. Similarly propellant in container 1e at a height of bed of 100 cm
fails to detonate at a height of ignition of 5 cm above the bottom of the container. However,
when the ignition in container 1e is raised to 35 cm above the bottom, detonation occurs with
a height of bed of 70cm. Presumably the propellant below the point of ignition offers additional
confinement.

3.3 Tests of Large Metal Pallet-Container and Wooden Pallets. (Containers 2, 3a and 3b)

Tests shown in Tables 3 and 4 were conducted in 30 cm diameter cylindrical steel containers
with propellant quantities less than 70 kg. In manufacture, storage and transport, propellants
are often in much larger containers such as drying boxes, storage boxes, pallet boxes carrying
about 500 kg or more. Tests conducted with smaller containers and smaller quantities of
propellant might not provide a good indication of the deflagration to detonation properties of
the propellants in these larger containers. To investigate this Frauenfelder conducted tests in
containers types 2, 3a and 3b. In some tests ignition was at 5 cm from the bottom on the central
axes and in other tests it was at the same height but 7 cm from a corner of the rectangular
container. Results of Frauenfelder's tests are reproduced as Table 5.

3.4 Conclusions from Large Scale Tests

The Swiss researcher[2] drew the following conclusions from these tests:

a) In a mildly ignited propellant charge no transition from deflagration to detonation will
occur provided that at least one of the following two conditions is met:

   i) The container has a weak point near the point of ignition, such that the weak point will
   open at a sufficiently low pressure to allow propellant and combustion gases to escape.

   ii) The height of the bed in an open container is less than the critical height of the bed.

b) The critical height of a bed depends largely on the specific surface of the propellant and
to some degree on the propellant temperatures.

TYPE OF CONTAINER	PROPELLANT TYPE	TEMP. (°C)	HEIGHT OF BED (cm)	MASS (kg)	POSITION OR IGNITER HEIGHTABOVE FLOOR OF CONTAINER (cm)	UPON VERTICAL AXIS OF SYMMETRY	7 CM DISTANT FROM A CORNER	COMMENT
2	3	14	72	620	5	X		a
		14	74	640	5		X	b
3a	3	14	74	624	5	X		c
		14	74	624	5		X	d
3b	3	11	61	499	5	X		e
		12	61	499	5	X		e
		8	61	499	5	X		e
		4	61	499	5	X		e
		5	61	499	5	X		e
		-5	61	499	5	X		e
		11	61	499	5		X	e

a = the walls of the container became badly distorted but did not rupture.

b = distortion of container negligible.

c = one large side wall broke and was forced out.

d = the container was nearly intact.

e = both large side walls broke and were forced out.

TABLE 5: RESULTS: ALL EXPERIMENTS RESULTED IN DEFLAGRATION[2].

The conclusion (a) (i) above: that a transition to detonation will not occur if a weak point in a container will open at a sufficiently low pressure to allow combustion gases to escape, is important. In essence it means that if self-venting of the container can occur by rupture at a low pressure the contents will not undergo transistion to detonation. In the U.S.A., process containers have been designed with a high degree of venting area in order to reduce the potential for detonation.

4.0 STORAGE CONCEPT

The Swiss have recently reported on tests of a new concept for the storage of granular propellant[4].

This consists of storage buildings that have a number of storage rooms arranged side by side. At one end of these is a large common entrance room, Figure 1. Each room has a light valve type roof consisting of corrugated steel elements pivoted on one side and supported on the other by the crown of the wall. An outline is shown in Figure 2 and details are given in reference (4) including design and test results.

As a result of tests it was concluded that the building is suitable for the storage of propellants that are free of solvents. If solvent containing propellants are to be stored provision must be made to keep the solvent concentration in air below the solvent/air explosion level. The vented roof design is such that pressure within the building remains below 130 mbar for the authorized propellant storage quantity and conditions. Doors are specially designed to be flame proof.

Experiments have shown that in this building the possibilty of a deflagration-to-detonation transition is essentially non-existant provided that the following three conditions are met:

a) That the propellant is stored in "Wooden Europallets" of standardized European design. These have side walls of 19mm thick chip boards, no lids, and pallet floors covered with a standard coarse canvas sheet. Internal dimensions are 1162 x 762 x 610 mm high.

b) The propellant containers must be set up in the storage rooms so as to provide a free space of at least 30 cm by the side of each broad side (1162 mm side) of each container.
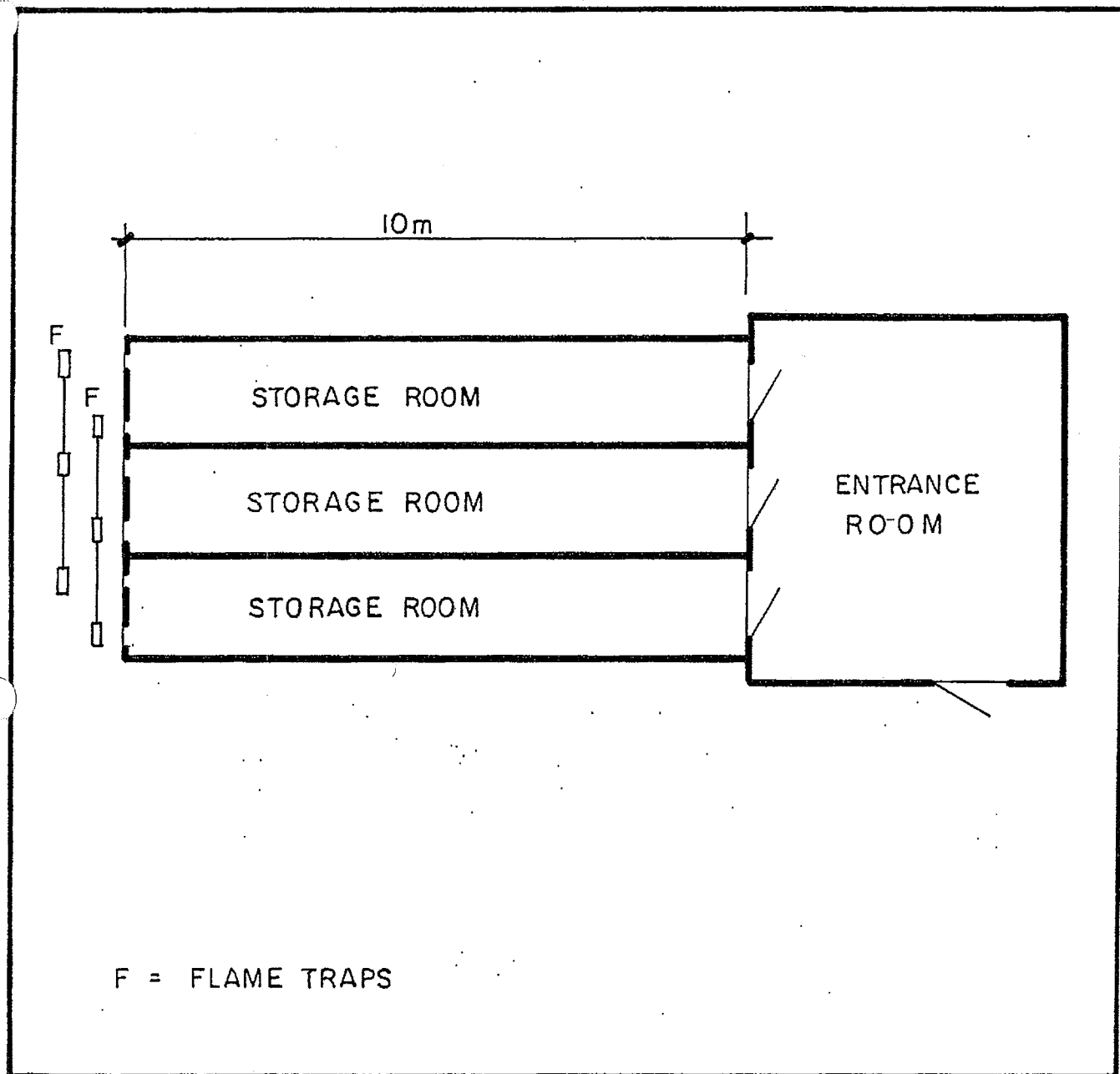
FIGURE 1: PLAN VIEW OF EXPERIMENTAL BUILDING.
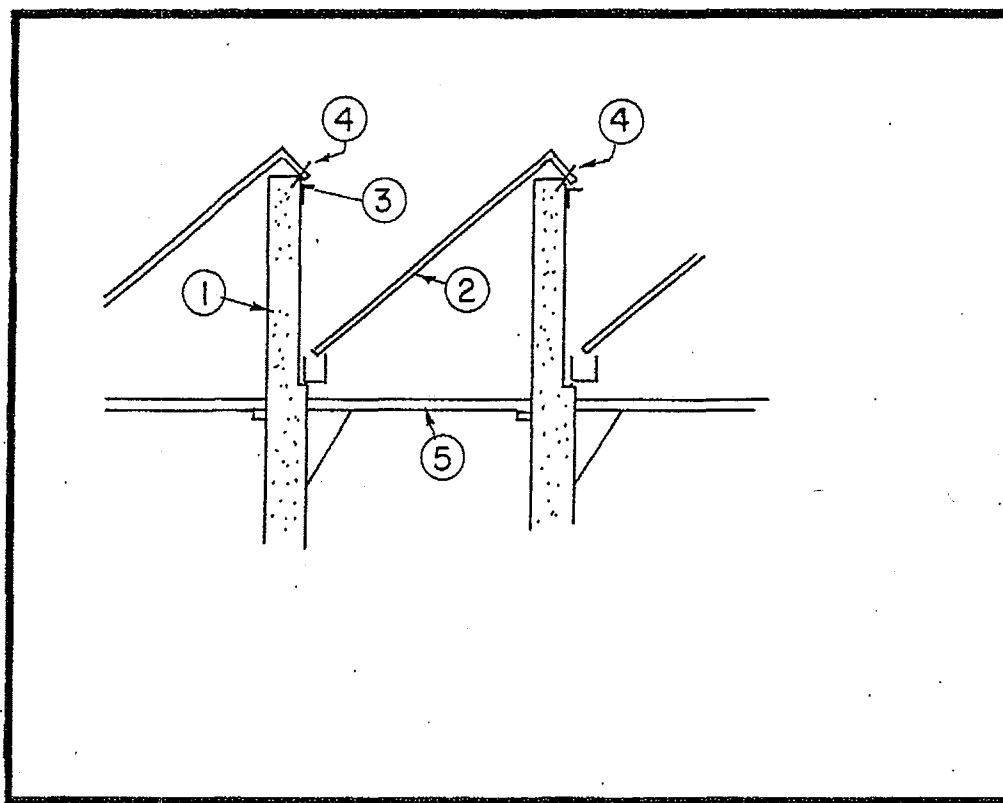
1. REINFORCED CONCRETE WALL
2. CORRUGATED STEEL ROOF ELEMENT
3. ANGULAR STEEL BAR - FOR DEFLECTION OF PROPELLANT
   GAS FLOW
4. BRASS WIRE TO FASTEN THE CORRUGATED ROOF ELEMENT
5. INSULATION MATTING

FIGURE 2 : ROOF DETAIL OF EXPERIMENTAL BUILDING.

This condition allows space for propellant and propellant gases to escape in the case of propellant deflagration within a container causing the side walls to break open.

c) The propellant temperature is less than 30°C and the height of the bed no more than; (i) 60 cm for propellants exhibiting a specific surface of less than $5.5 \, m^2/kg$ (web = 0.3 mm or 0.012 inch); (ii) 25 cm for propellants having a specific surface greater than $5.5 \, m^2/kg$ (web smaller than 0.3 mm or 0.012 inch)

The heights of bed in (C) above are very small. The intent of this building design is clearly to eliminate the possibility of both detonation of stored propellants and the transmission of combustion from room to room or building to building.

5.0 References

1) Jorma Karhulahti, Inspector of Explosives, Finnish Ministry of defence (no date)

2) R. Frauenfelder. Propellants, Explosives, Pyrotechnics 8, 193 - 198 (1983)

3) Private Communication, B. Thomson, HSE, Buxton, England.

4) R. Frauenfelder. "Testing of a New concept for the Storage of Granular Propellant."
Propellants, Explosives, Pyrotchnics 8, 102 - 108 (1983)

APPENDIX F

UNITED KINGDOM

STUDIES OF PROPELLANTS - BURNING TO DETONATION

UNITED KINGDOM

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

The U.K. has had only one possible instance of a propellant burning to detonation. This was
in a commercial small arms factory and details were not well known or available.

In general much less work appears to have been done on the problem than in other countries
studied. U.K. investigations are primarily of two types:

    (a) Laboratory scale tests in a "Large Sealed Vessel" (76 mm I.D X 9.6 mm wall). This is
essentially a "go - no go" test depending on the number of fragments into which the vessel
is broken.

    (b) Large scale tests - based on variations of U.N. Test Series 6.

The U.K. has found that the results of the U.N. tests depend very much on the confinement
provided by the container itself and the confinement provided by the method of test - for
example in the stack and bonfire tests. Work is now underway using a smaller laboratory scale
test.

1.0 LABORATORY SCALE TEST ("LARGE SEALED VESSEL TEST")

This test is U.K. Sensitiveness Collaboration Committee No 3 Test No 10[1]. The test uses about
300 cu. cm of propellant. In the test the boundary between burning and explosion is based on
the number of fragments into which the vessel is broken. Less than 15 fragments is considered
to indicate burning only. Fifteen or more fragments is considered to indicate explosion in which
case they would tentatively classify the propellant as HD 1.1. The vessel is made from a
cold-drawn seamless mild steel tube, 76 mm internal diameter and 9.6 mm wall thickness. The
tube is closed at both ends and has an effective internal length of 450 mm. The test material
is filled to about 25 mm from the top and ignited at the centre by a 3 g SR 371 C igniter. Full

details of the test are given in SCC No 3, including methodology for assessing and reporting the results. HD classification is by comparison of the results from the material under test with those from a standard. The "standard" at present (1988), which is considered in the U.K. to be just in HD 1.3 is Cordite WMT 124/040 (double base propellant 65/30 NC/NG single tube, web 0.042 inches).

A material considered to be just in HD 1.1 is the single base NC powder FNH .014. This is 83% of 13.15N nitrocellulose, 10% DND, 7% stabilizers. However it should be noted that tests (not specified) performed in Australia class FNH 012 as HD 1.3.

1.1 Studies Underway

The U.K. is part way into a sealed vessel study of very fine web advanced experimental gun propellants of the triple base nitramine type. (Porous propellants are too expensive to make in small quantities). The sealed vessel is being "calibrated" against propellants which go HD 1.1 in the U.N. Test Series 6, especially Test 6 (c) Bonfire Test.

2.0 PACKAGED PROPELLANTS - U.N. TEST SERIES 6

The U.K., in general, accepts the U.N. method of classifying packaged explosives by assigning them to a particular hazard division and compatibility group. However U.K. tests have found that the precise packaging method is of fundamental importance in determining this classification. This finding agrees with findings of other countries which have found that the container material, e.g. fibre vs. steel or aluminum, and the height of the propellant in the container, have an important bearing in determining hazard division.

In containers there may be a critical height of propellant, above which the material will burn to detonation. The height of containers should thus be so designed as to preclude propellant heights that could lead to burning to detonation.

U.K. studies have also found that the method of confinement which is used in U.N. Class 1, Series 6 tests can itself be a significant factor in determining the behaviour of the propellant in the tests. For example, it was found that a particular propellant packed in cylindrical tubes exhibited HD 1.1 behaviour in the Series 6 tests when confined by sandbags but when

confinement was by other cylindrical tubes filled with sand the behaviour was as for HD 1.3. The conclusion was that in this and similar cases small variations in the extent of confinement had a significant effect on the behaviour of the propellant in the tests and hence on the hazard division to which it should be assigned.

3.0 PLANS

The U.K. plans to conduct a study aimed at determining conditions which will prevent burning to explosion or detonation under storage conditions. This study, a responsibility of the Explosives Storage and Transport Committee, (ESTC), has not yet started.

4.0 CHANGES TO QUANTITY - DISTANCE TABLES

Initially any changes that will be made will try to reclassify some propellants from HD 1.3 to HD 1.1. A TNT equivalence factor may be used to modify the value of Q.

5.0 TNT EQUIVALENCE IN BURNING TO DETONATION

In U.N. Test 6c the propellant may be somewhat confined, thus it is not easy to get a measure of peak overpressure or impulse if the material burns to detonation. Therefore RARDE relies on crater size to measure TNT equivalance.

6.0 FLEXIBILITY CONSIDERATIONS

As a result of large scale U.N. test Series 6 tests the U.K. has concluded that there may be instances in which a propellant which is classified as HD 1.1 may be safely stored with suitable packaging and confinement conditions, as if it were HD 1.3, thus allowing the storage of larger quantities of the propellant in a particular location.

7.0 GENERAL CONCLUSIONS

It is too early to draw any comprehensive conclusions from U.K. work and studies to date. However the following general conclusions can be drawn:

i) There are situations in which propellants will burn to explosion or detonation.

ii) The large sealed vessel test appears to be a useful tool to study the burning to detonation of propellants. However final classification will probably have to depend on larger scale tests.

iii) There are none of the common propellants which the U.K. would reclassify except small arms propellants in small web size - mainly single base propellants.

iv) The major problem is likely to be in packaging and storage. Under some of these conditions a propellant which tested as HD 1.3 might perform as HD 1.1, ie, might explode or detonate.

REFERENCES

1) United Kingdom Sensitiveness Collaboration Committee Test Manual SSC No 3, Test 10. February 1977.

APPENDIX G

UNITED STATES OF AMERICA

STUDIES OF PROPELLANTS - BURNING TO DETONATION

UNITED STATES OF AMERICA

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

U.S. data has been found to be particularly important to understanding the deflagration - to - detonation transition of propellants.

U.S. criteria for identifying the potential of a propellant to undergo this transition are based on propellant composition (primarily percentage of nitrocellulose and nitroglycerine) web size, and perforation and can be applied to virtually any single or double base gun or small arms propellant for initial categorization of hazard division.

These criteria have been adopted by the Netherlands and further modified to include porous propellants and propellants under process-containing solvents.

U.S. accidents in blending towers and tests of vented and unvented containers in full size and sub-scale size have demonstrated the importance of venting to reduce the tendency of a sensitive propellant to undergo a deflagration - to - detonation transition.

1.0 ACCIDENTS

Accidents in which propellants have burned to detonation have probably occurred in the U.S.A. However, in the time available for this study we did not discover any reports on these.

Important information on two massive fires in blending towers was furnished by Mr. L. Saulnier of the EMR Explosives Branch. In spite of the very large quantities of propellants involved there was no transition to detonation in either case.

Both accidents took place in 1944.

1.1 Alabama Ordnance Works Fire

This fire occurred in a combined blending tower and pack shed. The top bin of the tower was charged with 26,400 pounds of FNH 0.0195 single base powder for 40 mm ammunition. there were also 98,250 pounds of the same granulation in the lower bin and loading hoppers. A total of 147,650 pounds was destroyed. The blending tower was completely destroyed but there was little damage to the pack shed because of a fire wall which separated it from the tower. There were 3 fatalities and 12 major injuries, all from burns. There was no indication of any part of the powder having detonated.

The cause of this fire was not determined. The percentage of dust in the batch was found to be well within acceptable limits and dust conditions throughout the building were said to have been normal before the fire. The point of ignition was not determined but was generally considered to be at the top of the tower. The following possible causes of ignition of powder or dust on the top floor were postulated as:

1) Dropping a powder buggy into the top bin.

2) Rolling a powder buggy wheel over a powder grain causing it to slide and ignite by friction.

3) Ignition of powder dust along the curb, caused by friction when the powder buggy is manoeuvered into dumping position.

4) Static electricity causing ignition of powder dust in the buggy during the dumping of the charge into the top bin.

5) Striking some metallic part of the buggy against the steel guard rails around the charging part or other metal parts of the building or, striking the metal parts of two buggies together.

Although this accident did not result in a transition to detonation a description of the accident and its possible causes have been included here for the following reasons:

a) It indicates that a propellant of this composition, form and web (single base, single perforated with web 0.0195 inches) probably does not readily undergo transition to

detonation, particularly if ignited from the top. If ignition had been at the bottom of the tower the self confinement of the propellant bed might have caused the transition to detonation to take place.

b) It may indicate that the large degree of venting in the tower minimized confinement.

1.2 Louisville Fire

The second blending tower fire was on 13 August 1944 at a propellant plant near Louisville Kentucky and involved about 28,000 pounds of M_3M_1 single base single perforated powder for the 105 mm gun. This was distributed as follows: - about 10,000 pounds in the upper bin; 3000 pounds in buggies on the elevator; the remainder (about 15,000 pounds) in the lower bin or in buggies under the bin.

The cause of the second fire was also not determined. Static electricity was considered to be an unlikely cause since the ambient relative humidity at the time of the accident was 75%. There is always evidence of the presence of a static change on this type of dry, unglazed single perforated powder.

The assumed cause was that the fire was started by impact or friction on powder grains or some foreign object. There were two points at which powder was apparently being moved. One buggy at least, was in some stage of the dumping operation on the top floor. Three buggies on the first floor after the fire showed strong indications of being loaded or in the process of filling. It was therefore concluded that the fire may have started on either the first or on the top floor.

The web of this propellant was not given. However since it is a single perforated cannon powder for 105 mm guns its web is likely to be about 0.015 inch. Propellants of this type and web are not likely to undergo transition to detonation in the absence of a reasonable degree of confinement, particularly if ignited from the top.

2.0 DEFLAGRATION TO DETONATION STUDIES OF GUN AND SMALL ARMS PROPELLANTS

2.1 Open Tube Tests (Hercules/Picatinny)

The critical explosion height for U.S. M1 SP propellant versus diameter was studied by Hercules Inc[1]. The propellant is single- base, single-perforated with a 0.013 inch web.

All tests were with Schedule 40 black seamless steel pipe open at the top and closed at the bottom with a standard pipe cap or other pipe fitting. Nominal diameters ranged from 1 inch to 18 inches. Wall thickness increased with diameter. The propellant was ignited at the bottom by a 12-gram bag igniter (50/50 mixture of FFFG black powder and 2056 casting powder). The bulk loading density of the propellant was about 0.6 g/cm^3. Pipe damage alone was used as the criterion for explosion. An "explosion" was based on rupture or a fragmented pipe and a "no explosion" was based on no damage to the pipe. It was not possible to differentiate explosion from detonation.

Results are shown in Table 1 and Figure 1[1]. The explosion height increases with diameter in a fairly linear relationship.

2.2 Open Tube Test - Naval Surface Weapons Centre

Richard R. Bernecker of the U.S. Naval Surface Weapons Centre[2] has reported on studies of commercial double base ball powders from two manufacturers as part of a broader study of the deflagration-to-detonation transition process for high-energy propellants. The parameters were: composition; particle size; shape; and to some extent, confinement. Confining tubes in most trials were steel 25.4 mm (1 inch) inside diameter, 76.0 mm outside diameter. In two test series the high confinement steel tubes were replaced by lexan low confinement tubes of the same dimensions. Results are shown in Table 2.

3.0 U.S. HAZARD CLASSIFICATION OF PROPELLANTS

The U.S. has established hazard classifications for propellants based on their potential for transition from burning-to-detonation[3,4]. This potential depends on web size, composition and

NOMINAL PIPE SIZE (inches)	INSIDE DIAMETER (inches)	WALL THICKNESS (inches)	CRITICAL HEIGHT TO EXPLOSION (inches)
1	1.05	0.13	7
2	2.07	0.15	12
4	4.03	0.24	13
6	6.06	0.28	16
8	7.98	0.32	22
18	16.88	0.56	32

All pipe - Schedule 40 black seamless steel.

TABLE 1: FLAME-INITIATED EXPLOSION CHARACTERISTICS OF M1 SP
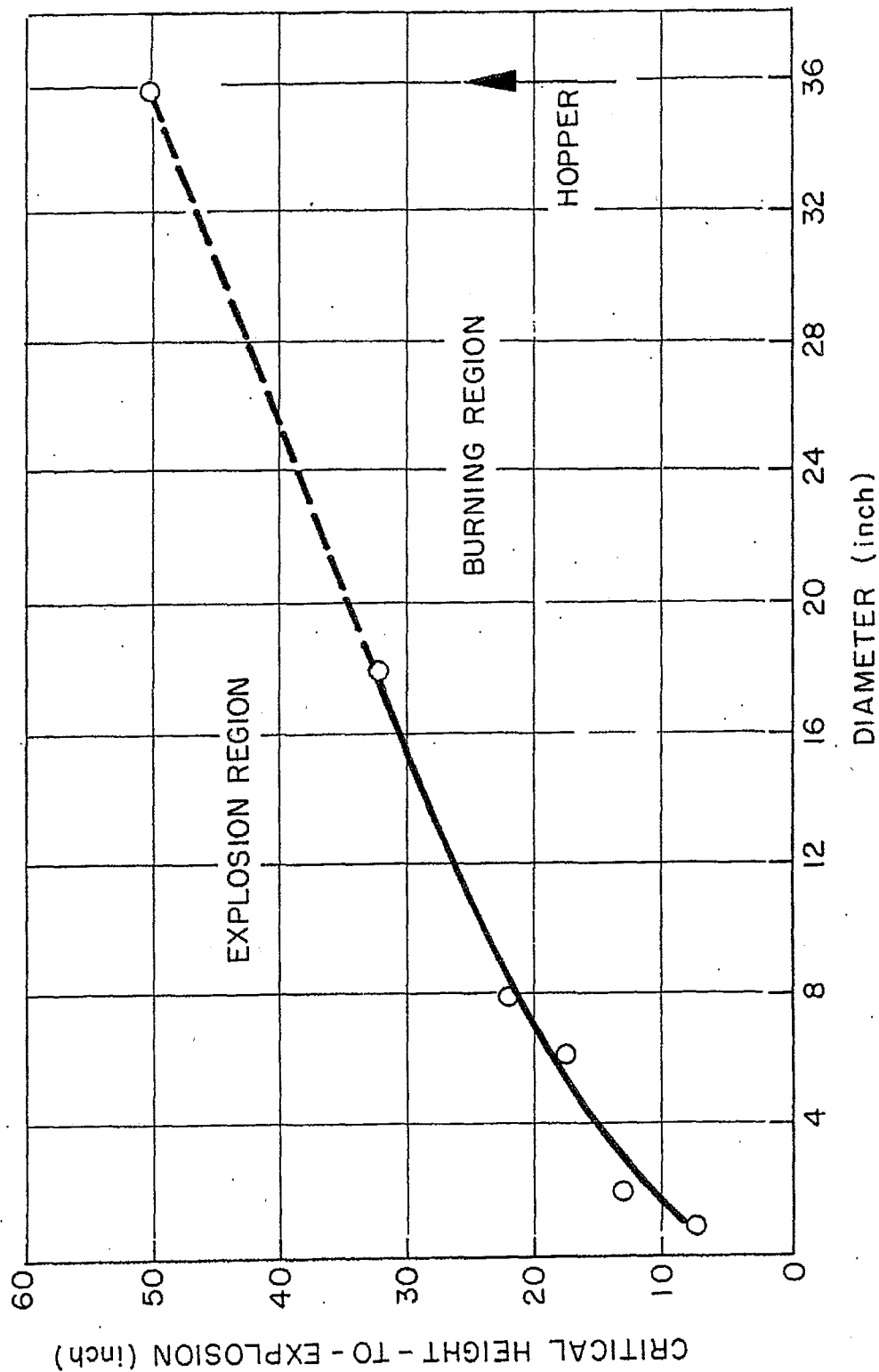PROPELLANT. (Single-Base, Single Perforated, 0.013 Inch Web)

FIGURE 1 : CRITICAL HEIGHT TO EXPLOSION AS A FUNCTION OF DIAMETER FOR MISP PROPELLANT.
(Values Beyond 18in Are By Extrapolation)

PROPELLANT		%NG	AV. PARTICLE DIAMETER		CONFINEMENT	CRITICAL DETONATION HEIGHT
			(mm)	(inches)		(mm)
Winchester	630	35	.65	.026	steel	160
	231	25	.80	.032	steel	121
	231	25	.80	.032	lexan	210
	630	35	.65	.026	lexan	280
Olin	WC 140	0	.4	.016	steel	368
	TS 3660	12.3	.7	.028	steel	330
	TS 3659	21.6	.4	.016	steel	199
	TS 3661	34.9	.7	.028	steel	298

The Winchester ball powder is roughly spherical The Olin powder is flattened spheres height/diameter 1/4.

TABLE 2: DEFLAGRATION - TO - DETONATION FOR NC/NG POWDERS

on the degree of confinement provided by the container, for example whether of wood or
metal, vented or unvented. The classifications based on these criteria are summarized in Table
3 from data of References 3 and 4.

This U.S. system has been adopted by the Netherlands, with modifications to include
propellants in the "in-process" stages. Both countries consider that confinement is important,
whether provided by the container or the self-confinement provided by the depth of the
propellant bed. The U.S., as will be seen from Table 3, emphasizes that venting can reduce the
potential for transition to detonation, i.e. change of hazard division from 1.3 to 1.1. Vented
Vessel tests are discussed in the next section.

4.0 VENTED VESSEL TESTS

The U.S. has carried out venting tests in both full scale and reduced scale process and storage
vessels.

4.1 Full Scale Vented Vessel Tests

These have been carried out by the Hercules Aerospace Division, Radford Army Ammunition
Plant for Picatinny Arsenal to establish a hazard classification for M1 SP Propellant for
Automated single base finishing operations. The objectives of the work were:

1) Design and test the venting adequacy of a proposed propellant storage hopper for
precluding explosive reactions when M1 SP propellant (for 105 mm ammunition) is flame
initiated.

2) Establish the hazard classification for 450 pounds of M1 SP propellant in these hoppers
for automated single base finishing operations (ASBL) air dry operations.

3) Define the flame initiated explosive characteristics of M1 SP propellant confined in
steel.

Objective 3 has been discussed in paragraph 2.1 above.

PROPELLANT	HAZARD DIVISION
Propellant, multiperforated, cannon and rifle, w/web thickness not greater than 0.019 of an inch (.475 mm)	1.3^2
Propellant, double base and composite grains found to be nonmass-detonating in tests conducted in accordance with TB 700-2	1.3
Propellant, double base and composite grains found to be mass-detonating in tests conducted in accordance with TB 700-2	1.1
Propellant grains, polysulfide-perchlorate, containing not more than 74 percent oxidizer	1.3
Propellant, single base, multi-perforated, w/web thickness greater than 0.019 inch (excluding single base propellant containing 98 percent or more nitrocellulose (NC)	1.3
Propellant, single base, containing 98 percent or more NC	1.1
Propellant, single base, single perforated (rifle)	1.3^2
Propellant, single base (FNH and NH compositions) single perforated, cannon, w/web thickness not greater than 0.033 of an inch (0.825 mm)	1.3^2
Propellant, single base, low pressure, for pistols and shotguns, etc.	1.3^2
Propellant, double base, containing not more than 20 percent nitroglycerin (NG), w/web thickness of 0.0075 of an inch or greater (0.19 mm)	1.3^2
Propellant, double base (for artillery ammunition) containing over 20 percent NG	1.1
Propellant, double base, w/web thickness less than 0.0075 of an inch, regardless of NG content	1.1

[2]Class 1.3 applies when stored in metal-lined wood boxes; when stored in all-metal containers not designed for quick release of pressure, class 1.1 applies.

TABLE 3: HAZARD CLASSIFICATION OF PROPELLANTS

Objectives 1 and 2 involved studies in vented and unvented drying hoppers of 36 inch square cross section.

In the unvented hoppers, exceeding an 18 inch critical bed depth changed the in-process hazard classification from "burning hazard" to " explosive hazard". The quantity of propellant at 18 inches of bed depth was less than 250 pounds.

The existing hopper, because of baffles, had only a 2.25 sq ft top venting area. The addition of 8 top side vents and 8 bottom side vents, Figure 2 from Ref 1, increased the total vent area to 9.69 sq ft.

Tests established that a propellant surface to hopper vent area of about 660:1 or less is more than adequate for preventing violent explosive reaction for 450 lbs of M1 SP propellant. The height of bed for this weight is about 29 inches. The larger the web (or conversely the smaller the surface area) the less chance of a violent reaction.

In the test with 450 lbs of M1 SP propellant about 150 lbs of unburned propellant were estimated to have been expelled from the hopper and did not contribute to gas generation within the hopper.

4.2 Reduced Scale Vented Vessel Tests

The full scale hopper tests described in 4.1 above were successful in resolving an immediate problem with a particular propellant in a particular equipment. However there are the disadvantages of: a) cost of test vessels

b) large quantity of propellant required

For this reason the Hercules Company at the Radford Army Ammunition Plant[4] has carried out a program to test lesser quantities of propellant in relatively low cost subscale vessels and to correlate the results to full scale models.

The impetus for the study was the propellant drying operation involving 680 kg of M26 double base propellant in which the nitroglycerin content was greater than 20 percent. This operation would normally require the propellant to be classified as hazard division 1.1, and would require
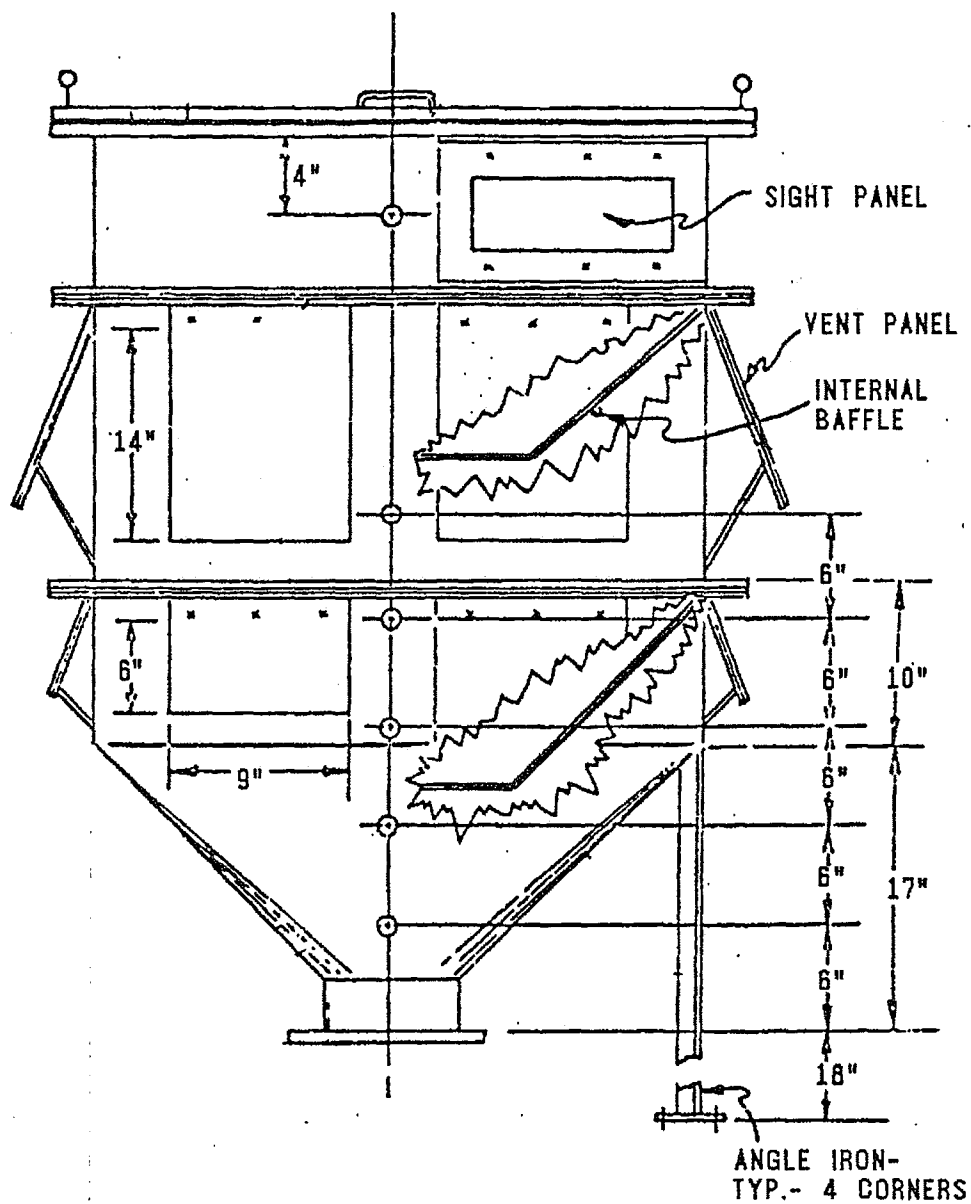
SIDE VIEW OF HOPPER

FIGURE 2 : REVISIONS TO BASIC HOPPER DESIGN.

a much higher facility cost than if the propellant at this stage of manufacture could be classified
as H.D. 1.3.

The scale model tests were with three different size vessels, tested at various levels of vent
area to determine the effects of vent area and scale size on the pressurization rate for the
propellant. The test vessels were scaled to the drier size as 1/4, 1/3, and 1/2 scale and propellant
weights were scaled according to the cube of the vessel scaling factor. Results are summarized
in Table 4 from Reference 4 and plotted as scaled rate of pressure rise versus scaled vent area
in Figure 3

4.3 Mathematical Modeling of Scaled Venting

Figures 3 and 4 and the mathematical modeling discription are taken directly from the paper
by Evans, Kristoff and Bolleter . Their work provides a method by which the rate of rise of
pressure in any process vessel can be calculated from subscale test results. From this it is then
possible to determine whether the vessel has sufficient venting to prevent the transition to
explosion or detonation.

The description of the modeling process, after Evans, Kristoff and Bolleter follows:

Math Modeling

The curve shown in Figure 3 is best described by the equation $P = a\overline{A}^{-b.}$ Since $\overline{A}$ is directly
related to the vent ratio R, the equation can be rewritten as $P = aR^b$. Thus the rate of pressure
rise is a function of both propellant surface area, S, and vessel vent area, A_v, since by definition
$R = S/A_v$.

The curves in Figure 4 show a decrease in rate of pressure rise as vessel scale increases at a
constant vent ratio. This effect can be shown to be caused by the scale factor Λ as follows. The
subscale vessel produces the same maximum pressure at a given vent ratio as the full-scale
vessel, i.e., $P = aR^m$, and the pressure rate of rise in a full-scale vessel is $P = P/t$. However,

SCALE	PROP. WT. (kg)	VENT RATIO RANGE	MAX. PRESSURE, RANGE (kPa)	RATE OF PRESSURE RISE RANGE (MPa/s)
1/4	10.6	800-1500	758-2041	43.6-53.6
1/3	25.2	500-1100	146-1717	4.1-47.3
1/2	85.0	267-1100	74-1151	2.9-21.2

TABLE 4: RANGE OF RESULTS OF SUBSCALE TESTS
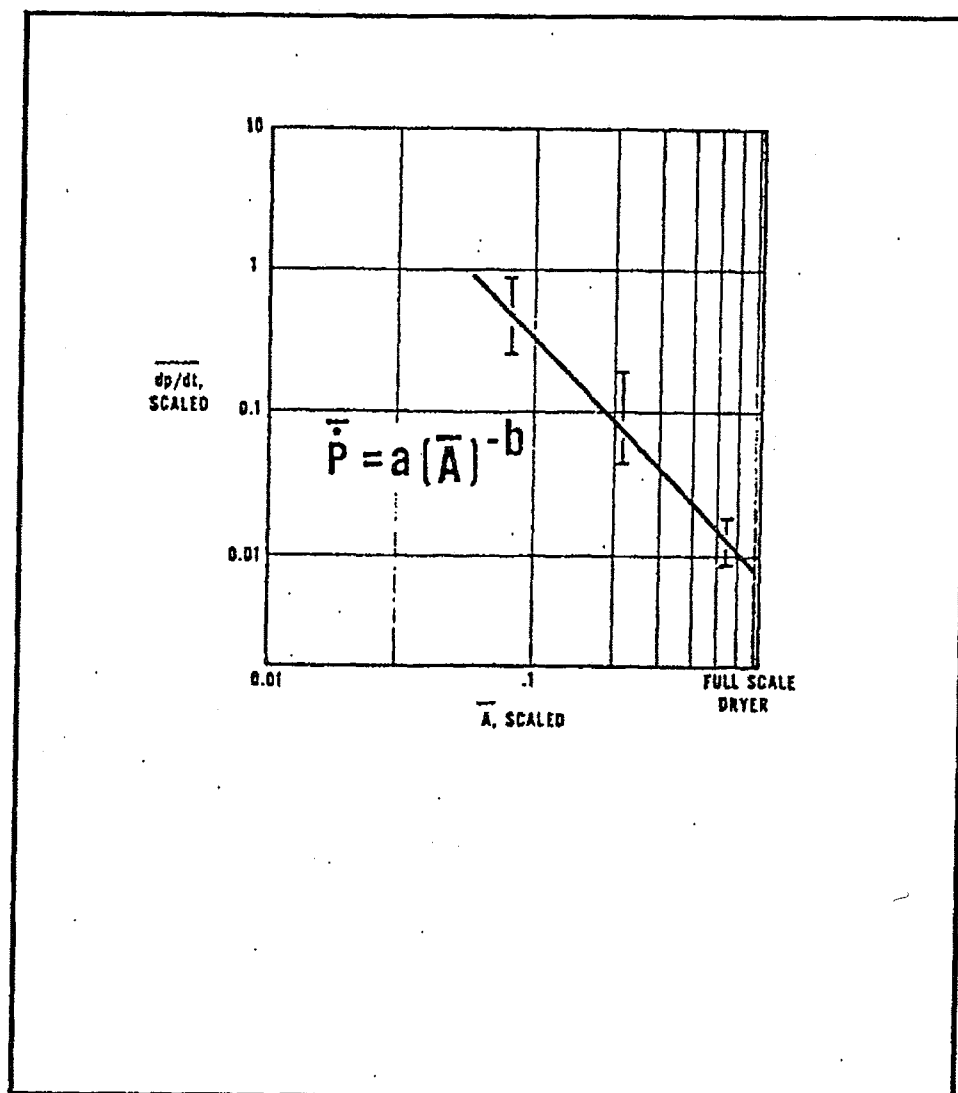
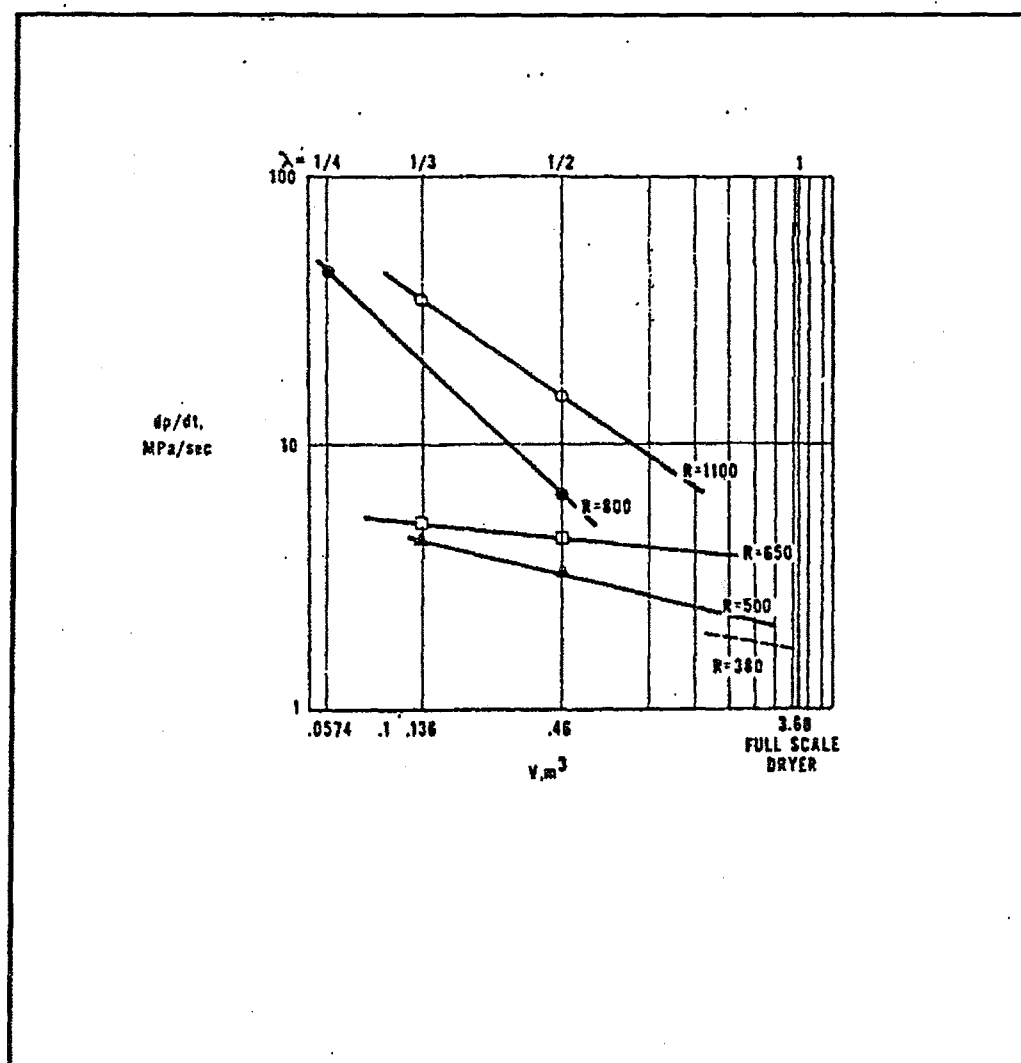FIGURE 3 : SCALED RATE OF PRESSURE RISE VERSUS SCALED VENT
AREA.

FIGURE 4 :   RATE OF PRESSURE RISE VERSUS SCALE AT CONSTANT
             VENT RATIO.

since a subscale vessel contains less propellant than the full-scale vessel, the burning distance is reduced by Λ. The burning time in the subscale vessel is also reduced by Λ, and the rate of pressure rise becomes

$$\dot{P}_{subscale} = \frac{P}{\Lambda \ t}$$

Thus the pressure rate of rise is seen to increase with a decrease in vessel size.

The relationship in the pressure rate of rise between full and subscale vessels of constant vent ratio is therefore

$$\dot{P}_{fullscale} = \Lambda \ \dot{P}_{subscale}$$

Where vent ratio is not constant, the relationship becomes

$$\dot{P} = \dot{P}_0 \ f(R, \Lambda, R \Lambda).$$

For propellants of different formulations, differences in values for c and n from the propellant burning rate equation $r = cP^n$ must be considered. To construct a model for all propellants requires the addition of these terms to obtain the form

$$\dot{P} = \dot{P} \ f(R, \Lambda, R \Lambda, c, n)$$

Thus the rate of pressure rise in any process vessel can be calculated from subscale test results. By knowing the strength of the process vessel as a function of rate of pressurization, it will be possible to determine whether the vessel will vent, rupture from overpressurization, i.e., explode or transit to a detonation. To preclude a calculated detonation, the vent area of the vessel should be increased. To prevent damage from a calculated overpressurization, more venting could be provided and/or use lower strength materials of construction for all or part of the vessel to allow the vessel to rupture at relatively low pressures.

5.0 REFERENCES

1) C.H. Johnson and R. Rindner "Explosive Tests for Establishing Hazard Classification for M1 SP Propellant in Automated Single-Base Finishing Operations". Picatinny Arsenal Technical Report 5020.

2) Richard R. Bernecker "The Deflagration - to - Detonation Transition Process for High Energy Propellants - A Review." AIAA Journal Vol 24, No 1, Feb 1986.

3) U.S. Department of Defense Contractors Safety Manual for Ammunition and Explosives.

4) J.L. Evans, F.T. Kristoff and W.T. Bolleter "Establishment of Propellant Hazards Classification via Vented Vessel Testing" Hercules Aerospace Division, Radford Army Ammunition Plant, Radford, U.S.A.

Appendix H
Test shot 2 charge
Photograph by S/A Steven L. Beggs

Bullseye

Smokeless pistol powder
Billions of rounds have been loaded with Bullseye since it was introduced in 1913.

- Fast burning and consistent
- Economical and accurate
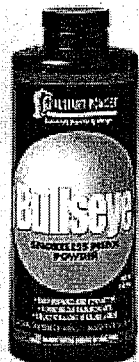
Relative Quickness	100%
Principal Purpose	Handgun loads
Remarks	America's best known pistol powder. Unsurpassed for .45 ACP target loads
Safety Data	MSDS
Canister Sizes	
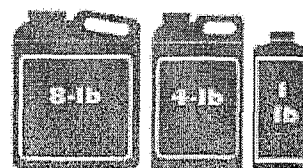
*Relative Quickness (RQ) is a measure of a powder's burning speed comparing it to Bullseye, our fastest burning powder at 100%. Example: Red Dot Powder's RQ is 94.1%. This means Red Dot burns 5.9% (100%-94.1%) slower than Bullseye.
RQ is not an absolute value. It cannot be used for selecting a powder for developing loads. Consult the "Reloaders' Guide for Alliant Smokeless Powders" for specific load recommendations.

> Return to Top

SHOOTERS WHO RELOAD WITH NEW RELODER 10X ARE A VERY CLOSE GROUP

If you take pride in your accuracy, NEW Reloder 10X Powder from Alliant will give you a lot to be proud of. Developed for the requirements of small caliber bench rest and varmint shooters, clean-burning Reloder 10X Powder delivers premium quality, superior consistency and out-standing performance. With minimum copper fouling and optimum velocity, Alliant 10X is THE POWDER OF CHOICE in light bullet 223 Rem and 22-250.
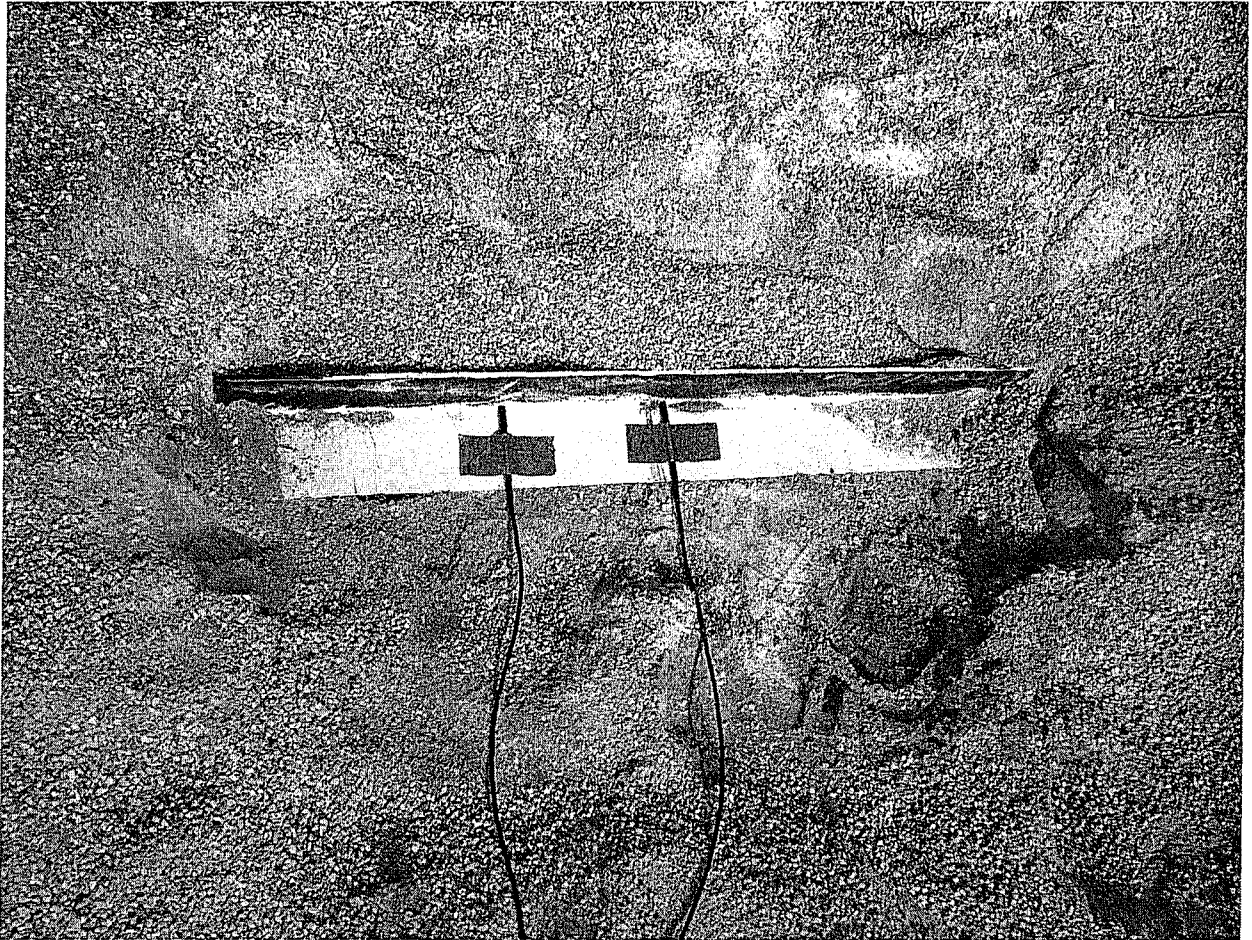
Appendix J
VOD Switches
Photograph by SA Steven L. Beggs

Appendix K
Test shot 2 prior to firing
Photograph by S/A Steven L. Beggs

Final Report

Double Base Smokeless Powder Velocity of Detonation

3 October 2007

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Executive Summary:

On 3 October 2007, ORA Inc. conducted a series of tests to evaluate the velocity of detonation (VOD) of commercially available double base smokeless powder. Testing was conducted at the request of Special Agent Steven Beggs, Bureau of Alcohol, Tobacco, Firearms, and Explosives (BATFE). Four separate six pound double base powder charges (Alliant Bullseye) were detonated. All charges were contained in plastic bread bags and were unconfined. A high speed switching circuit and crushable switches were used to measure the VOD of the unconfined powder charges. A high speed computer data acquisition system was used to record the output of the switching circuits.

Velocity of detonation was measured between 19,000 to 25,000 feet per second, with 3 of 4 measurements at 19,000 – 20,000 feet per second. Given the possible influence of charge/switch geometry on the VOD measurement, a conservative lower bound for VOD could be set at 15,000 – 17,000 feet per second.

Based on these tests it is concluded that the smokeless powder tested meets the definition of a high explosive – it detonates in an unconfined configuration using a number 8 commercial detonator with a conservative VOD between 15,000 – 17,000 feet per second.

Discussion:

Switch description:

Velocity of detonation is measured by determining the time between two switch closures with a predetermined distance between switches. The switches are single-use crushable coaxial switches. The switch consists of a short piece of soft copper tubing which is crimped and in electrical contact with the shield of a length of RG 58 coaxial cable. The insulation is stripped from a short length of the central conductor and the central conductor is contained within the copper tube. A short piece of insulating material is placed on the far tip of the central conductor to ensure electrical isolation between the central conductor and the copper tube. Figure 1 shows the copper tube and the RG 58 shield conductor and central conductor before the copper tube is crimped into place.

Figure 1: crushable switch (disassembled)

Note the insulating tip on the central conductor that ensures an air gap between the central conductor and copper tube maintaining electrical isolation during normal handling and placement.

When the switch is subject to a detonation wave the copper tube crushes and makes electrical contact with the central connector completing the circuit.

Monitoring circuit:

In order to detect the completion of the electrical circuit when the switches are crushed, the switches must be placed in an active circuit that will allow detection of a switch in the closed position. The circuit used with the crushable VOD switches is a simple resistive loop with a 9 vdc power source in series. Figure 2 shows a schematic of the sensing circuit.
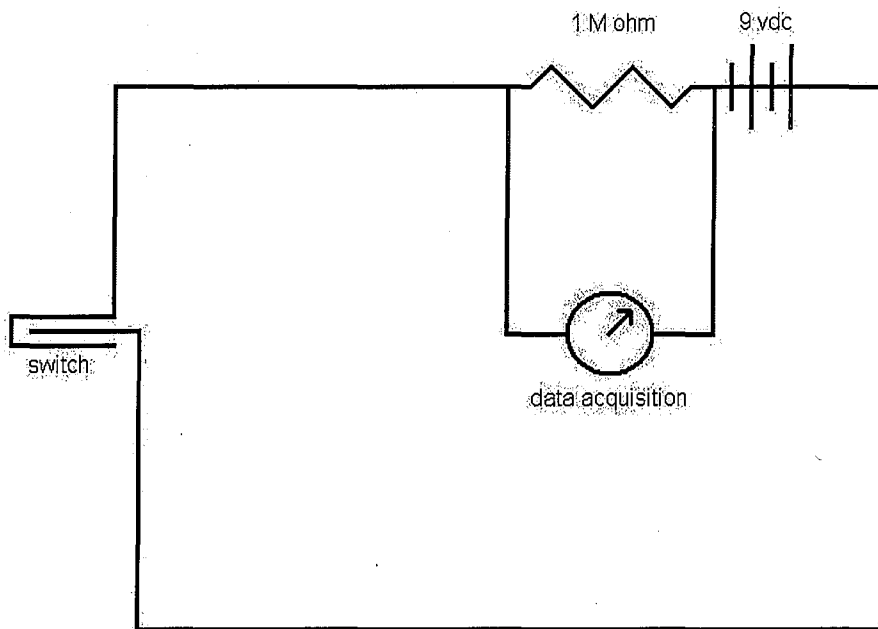

Figure 2: sensing circuit

The 1 M ohm voltage sensing resistor serves to limit amperage in the circuit and provide an input to the data acquisition system. Data is acquired using a National Instruments 6110E data acquisition board in a desktop PC. A total of 5,000,000 samples per channel are collected at a sample frequency of 1 MHz.

To measure VOD, a minimum of two switches are required separated by a predetermined distance (8 inches). Each switch has its own dedicated sensing circuit and its own dedicated data acquisition channel. Figure 3 shows the arrangement of two switches for an actual shot.
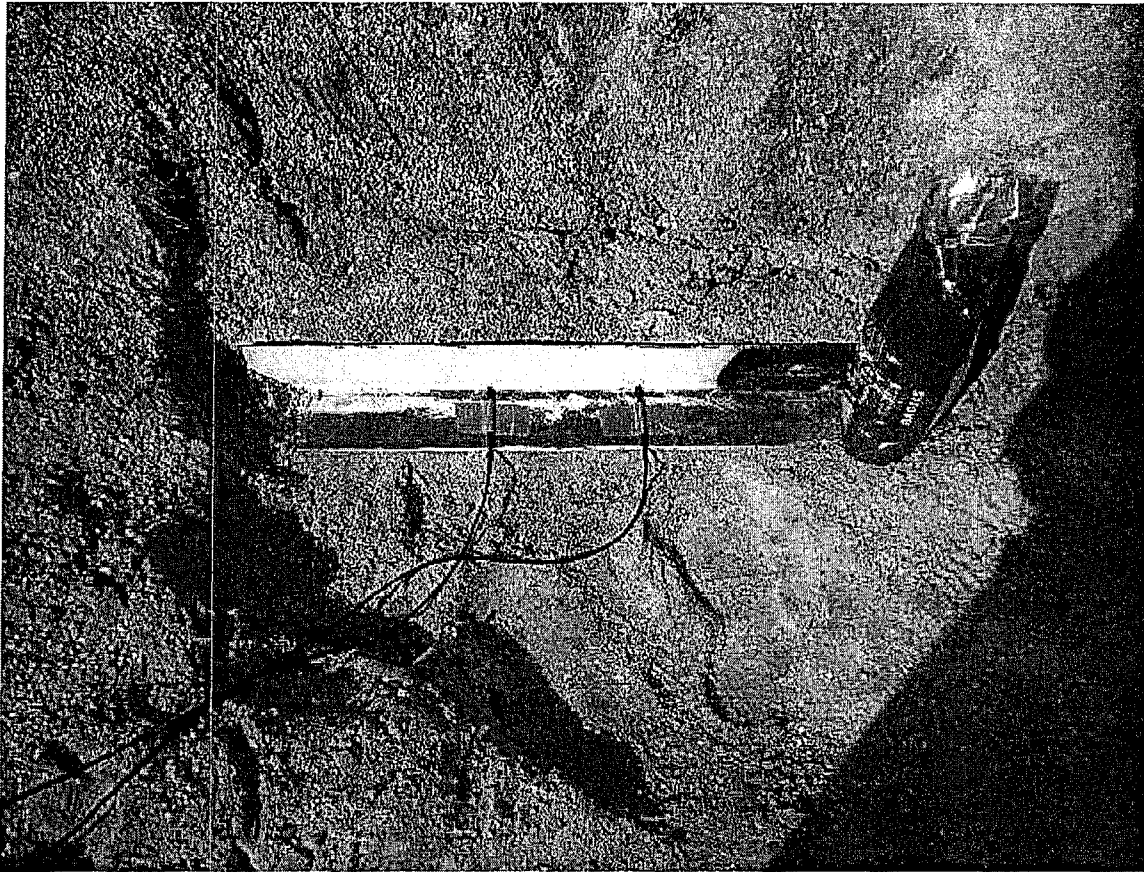
Figure 3: arrangement of crushable switches

The powder charge, shown to the right, will be placed on top of the switches prior to the shot. The completed charge measures 10 inches long with a circumference of 5 inches. The charge weight for each test is below:

1. Test charge weight: 5.980 lbs

2. Test charge weight: 5.955 lbs

3. Test charge weight: 6.150 lbs

4. Test charge weight: 6.135 lbs

Note the switches are wrapped in electrical insulating tape to isolate them from the conductive steel plate beneath the charge. If the outer copper tube of both switches were allowed to be in electrical contact with the steel plate, it would provide a leakage path from circuit 1 to circuit 2. Once switch 1 crushed, the source voltage from circuit 1 would be applied to the outer copper tube of switch 2. This would cause voltage in

circuit 2 to rise simultaneously with circuit 1, invalidating the VOD measurement. Figure 4 shows the arrangement.
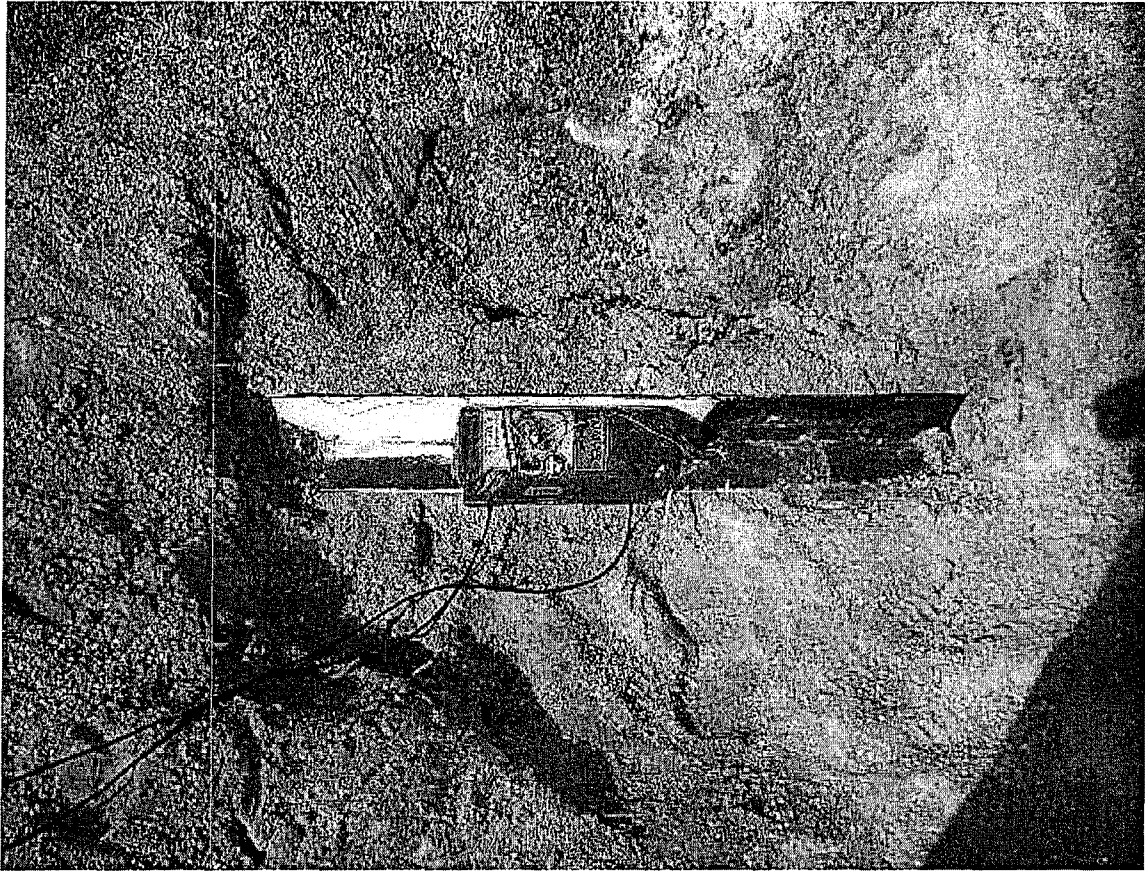

Figure 4: Arrangement for shot

Prior to detonation, all switches are open, no current flows in the circuit, and output voltage across the sensing resistor is zero. When subject to the detonation wave, the switch crushes and makes electrical contact between the outer copper tube and the inner conductor. Current flows and voltage output across the sensing resistor rises to approximately 9 vdc. The switch is totally destroyed by the detonation wave and the output may ultimately drop to zero when the switch is destroyed. However, given the high speed output of the switch and the simple resistive circuit, an output is measured for a sufficiently long time to observe the voltage rise to 9 vdc. The data recorder is triggered simultaneously for both channels and the velocity of the detonation wave is determined by the time lag between the rising voltage output of the two sensing circuits.

Results:

Output:

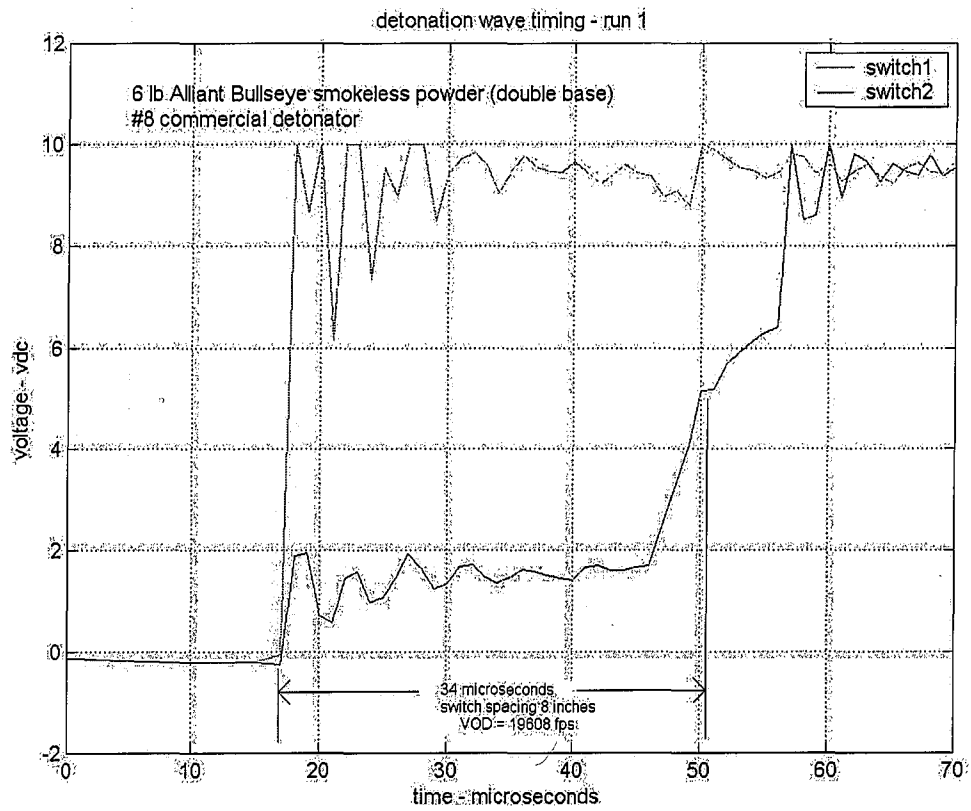Figures 5-8 show the output for four separate test runs:
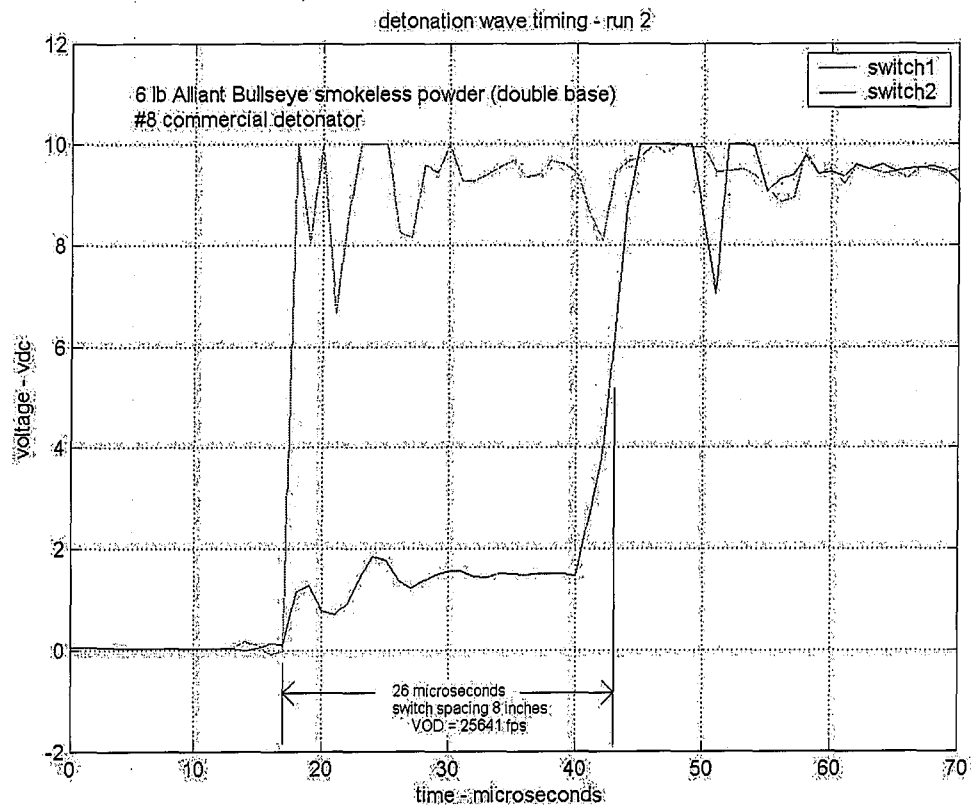
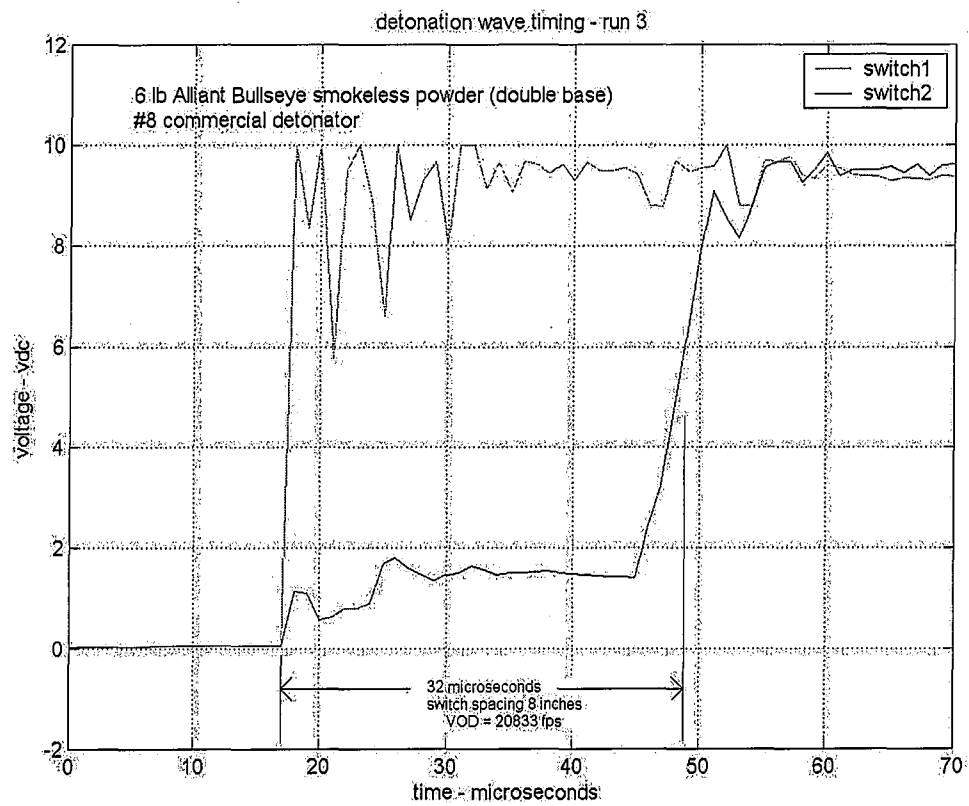Figure 5: run 1output

Figure 6: run 2 output
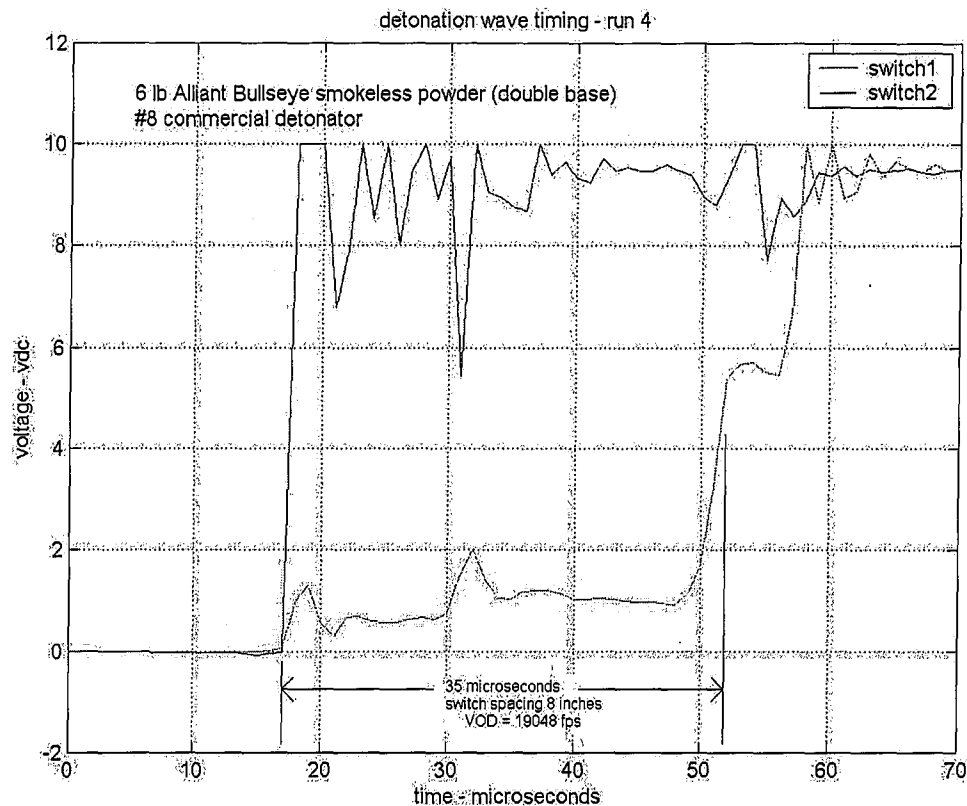
Figure 7: run 3 output

Figure 8: run 4 output

The graphs consistently show the voltage rise of both sensing circuits. The first switch consistently shows a cleaner make with a shorter rise time. The suspected reason for this is that this switch is located close to the detonator and this may aid in crushing the switch. The second switch consistently shows a slower rise time. This difference is suspected to be caused by a change in arrival angle of the detonation wave. The detonation wave is most likely arriving at switch 1 with a more normal angle of incidence. The angle of incidence at switch 2 is likely arriving at a more oblique angle as the detonation wave transitions from spherical propagation in it's early stages to more planar propagation in its later stages. Figure 9 shows this effect.
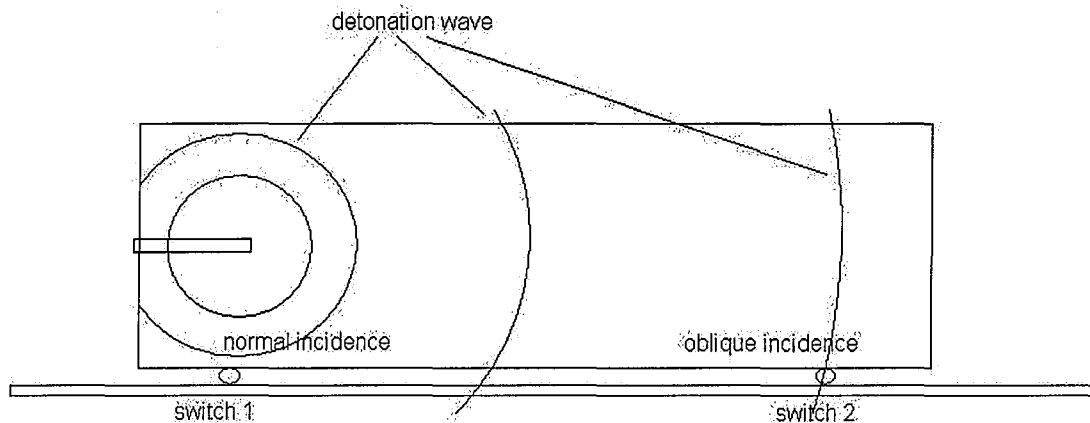
Figure 9: detonation wave incidence at switches

A slight increase in voltage is consistently observed in sensing circuit #2 immediately after the initiation of detonation. This is believed to be caused by the electrical leakage between circuit 1 and circuit 2 described above. The voltage doesn't fully rise to 9 vdc because it is mitigated by the electrical insulation wrapped around switch 2 and the high resistance of the steel plate between the switches. This artifact can be minimized by improving the insulation of the switches and by using a better insulated support surface, i.e. use bakelite board overlay on the steel plate. This minor artifact does not mask the actual closure of switch #2 and does not affect the measurement of the VOD. The closure time of switch #2 is taken to be the midpoint of the voltage rise by convention.

Disturbance of the position of switch 2 prior to the arrival of the detonation wave is not believed to occur since there is no physical mechanism to transmit vibration or overpressure that propagates faster than the detonation wave.

Table 1-1. Characteristics of US demolitions explosives

Name	Applications	Detonation Velocity		RE Factor*	Fume Toxicity	Water Resistance
		Min/Sec	Ft/Sec			
Ammonium nitrate	Cratering charge	2,700	8,900	0.42	Dangerous	Poor
PETN	Detonating cord Blasting caps Demolition charges	8,300	27,200	1.66	Slight	Excellent
RDX	Blasting caps Composition explosive	8,350	27,400	1.60	Dangerous	Excellent
Trinitrotoluene (TNT)	Demolition charge Composition explosive	6,900	22,600	1.00	Dangerous	Excellent
Tetryl	Booster charge Composition explosive	7,100	23,300	1.25	Dangerous	Excellent
Nitroglycerin	Commercial dynamite	7,700	25,200	1.50	Dangerous	Good
Black powder	Time fuse	400	1,300	0.55	Dangerous	Poor
Amatol 60/20	Bursting charge	4,900	16,000	1.17	Dangerous	Poor
Composition A3	Booster charge Bursting charge	8,100	26,500	---	Dangerous	Good
Composition B	Bursting charge	7,800	25,600	1.35	Dangerous	Excellent
Composition C4 (M112)	Cutting charge Breaching charge	8,040	26,400	1.34	Slight	Excellent
Composition H6	Cratering charge	7,190	23,600	1.33	Dangerous	Excellent
Tetrytol 75/25	Demolition charge	7,000	23,000	1.20	Dangerous	Excellent
Pentolite 50/50	Booster charge Bursting charge	7,450	24,400	---	Dangerous	Excellent
M1 dynamite	Demolition charge	6,100	20,000	0.92	Dangerous	Fair
Detonating cord	Priming, demolition charge	6,100 to 7,300	20,000 to 24,000	---	Slight	Excellent
Sheet explosive M118 and M186	Cutting charge	7,300	24,000	1.14	Dangerous	Excellent
Bangalore torpedo, M1A2	Demolition charge	7,800	25,600	1.17	Dangerous	Excellent
Shaped charges M2A3, M2A4, and M3A1	Cutting charge	7,800	25,600	1.17	Dangerous	Excellent

*TNT equals 1.00 relative effectiveness (RE).

Appendix M
United States Department of the Army
Washington, DC
Field Manual 5-250
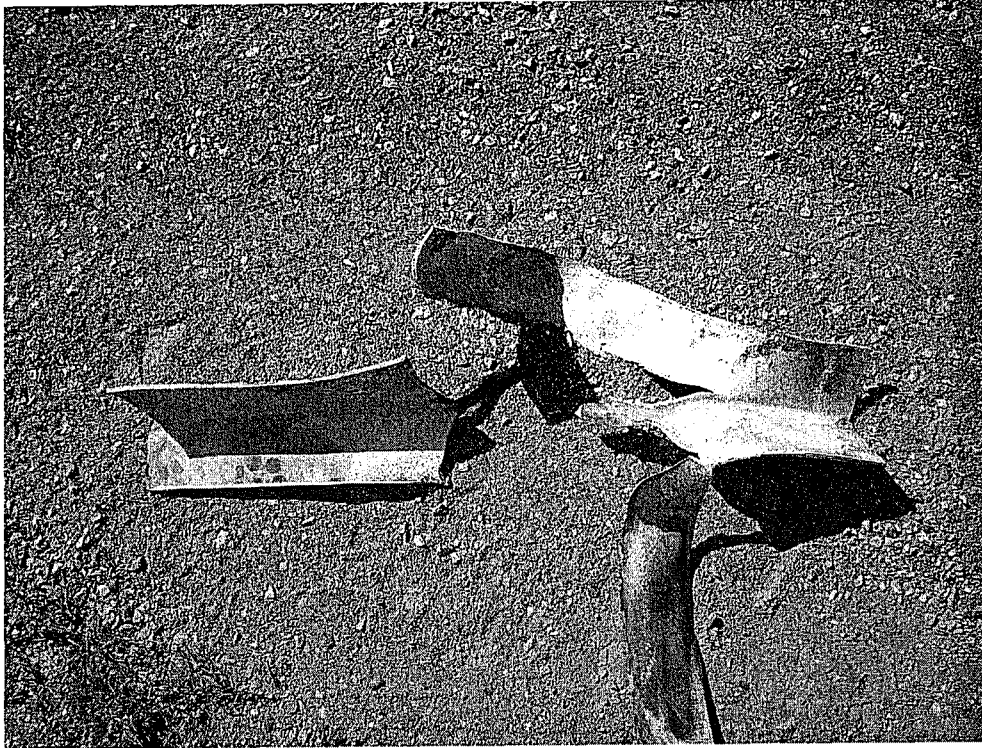## Chapter 1, Page 1-2
30 July 1998

Exhibit N
Witness Plate After Test
Photograph by SA Steven L. Beggs

Notes

[1] Annual Threat Assessment of the Director of National Intelligence, page 6.

[2] The Manufacture of Smokeless Powder http://www.fbi.gov/hq/lab/fsc/backissu/april2002/mccord.htm

[3] National Research Council, 1998

[4] ATF Publication 5400.7, page 91.

[5] ATF Intelligence Report, Explosive Filler Materials (Appendix E).

[6] Ibid (Appendix E)

[7] www.saami.org

[8] G.I. Brown, *The Big Bang: A History of Explosives*, page 134-137.

[9] G.I. Brown, *The Big Bang: A History of Explosives*, page 134-147.

[10] National Research Council, *Black and Smokeless Powders*, page 162.

[11] Ibid, page 20.

[12] ATF Forensic Chemist Cynthia Wallace email, March, 2008.

[13] Ibid, page 20.

[14] Ibid, page 21.

[15] *The Manufacture of Smokeless Powder* http://www.fbi.gov/hq/lab/fsc/backissu/april2002/mccord.htm

[16] Ibid

[17] John Conkling, *Chemistry of Pyrotechnics and Explosives*, page 139.

[18] Nurul Alam, *Dictionary of Explosives and Explosions,* page 316.

[19] Rudolf Meyer and Josef Kohler, *Explosives,* page 240 -245.

[20] ATF Publication 5400.7 Federal Explosive Law and Regulation, page 98.

[21] ATF Report to Congress, *Preventing the Illegal Use of Explosive Materials*, page 28.

[22] ATF Publication 5400.7 Federal Explosive Law and Regulation, page 91.

[23] Ibid, page 13.

[24] Ibid, page 48.

[25] Ibid, page 13.

[26] Ibid, page 43.

[27] Ibid, page 69.

[28] http://www.cabelas.com/link-12/product/0009716210742a.shtml

[29] ATF Intelligence Report, Explosive Filler Materials (Appendix E)

[30] ATF Report to Congress, *Preventing the Illegal Use of Explosive Materials*, page 27.

[31] ATF Publication 5400.7 Federal Explosive Law and Regulation, page 1.

[32] Tenney Davis, *Chemistry of Powder and Explosives*, page 4.

[33] Rudolf Meyer and Josef Kohler, *Explosives,* page 76.

[34] Ken Okada, *Detonation Velocities of Single and Double Base Powders*, Appendix F.

[35] Ibid, Appendix F.

[36] Mining Resource Engineering, *The Deflagration to Detonation of Transition of Gun and Small Arms Propellants,* page 1.

[37] Mining Resource Engineering, *The Deflagration to Detonation of Transition of Gun and Small Arms Propellants,* page 1.

[38] Mining Resource Engineering, *The Deflagration to Detonation of Transition of Gun and Small Arms Propellants,* page 1

[39] U.S. Department of the Army, FM 5-250, Chapter 1, Page 1-2.

[40] USDOJ OIG Report, Sections C and G.

[41] USDOJ OIG Report, Sections C and G.

[42] USDOJ OIG Report, Sections C and G.

[43] National Research Council, *Black and Smokeless Powders*, preface, page vii.

[44] Ibid, preface, page vii.

[45] Ibid, page 55 and 94.

[46] Ibid, page 27.

[47] Ibid, page 28.
[48] TSWG IED Awareness for First Responders Training Support Package
[49] TSWG IED Awareness for First Responders Training Support Package
[50] http://www.nraila.org/Issues/FactSheets/Read.aspx?ID=64
[51] Defense Intelligence Agency, Joint Intelligence Task Force Special Assessment, *Worldwide: Threats from Bulk Ammonium Nitrate*, page 1.
[52] Annual Threat Assessment of the Director of National Intelligence, page 6,7.
[53] Nurul Alam, *Dictionary of Explosives and Explosions*, page 100.
[54] Nurul Alam, *Dictionary of Explosives and Explosions*, page 109
[55] J. Akhavan, *The Chemistry of Explosives*, page 52.
[56] Nurul Alam, *Dictionary of Explosives and Explosions*, page 105.
[57] J. Akhavan, *The Chemistry of Explosives*, page 53.
[58] Nurul Alam, *Dictionary of Explosives and Explosions*, page 116.
[59] J. Akhavan, *The Chemistry of Explosives*, page 53.
[60] Nurul Alam, *Dictionary of Explosives and Explosions*, page 123-125.
[61] J. Akhavan, *The Chemistry of Explosives*, page 52.
[62] J. Akhavan, *The Chemistry of Explosives*, page 52.
[63] Nurul Alam, *Dictionary of Explosives and Explosions*, page 255-266.
[64] Nurul Alam, *Dictionary of Explosives and Explosions*, page 291.
[65] Robert Heramb, *The Manufacture of Smokeless Powder and Their Forensic Analysis*
    http://www.fbi.gov/hq/lab/fsc/backissu/april2002/mccord.htm
[66] ATF Publication 5400.7 Federal Explosive Law and Regulation, page 13.
[67] Nurul Alam, *Dictionary of Explosives and Explosions*, page 429.
[68] Nurul Alam, *Dictionary of Explosives and Explosions*, page 450.
[69] Nurul Alam, *Dictionary of Explosives and Explosions*, page 460.

Bibliography

Akhavan, J. *The Chemistry of Explosives (Rsc Paperbacks)*. London: Royal Society of
   Chemistry, 2004.

Alam, Nurul. *Dictionary of Explosions & Explosives*. Bangladesh: ISEE Explosives Engineers,
   2005.

Bureau of Alcohol, Tobacco, Firearms and Explosives Publication 5400.7, *Federal Explosives
   Laws and Regulations*. Washington, DC, 2007.

Brown, G.I. *The Big Bang, Third Edition*. Chicago: Sutton Publishing, 2005.

Conkling, John A. *Chemistry of Pyrotechnics and Explosives (Chemical Industries)*. Boca
   Raton: CRC, 1985.

Crowl, Daniel. *Understanding Explosions*. New York, New York: American Institute of
   Chemical Engineers, 2003.

Davis, Tenney L. *The Chemistry of Powder and Explosives*. Las Vegas, NV: Angriff Press, 0.

Davis, William C., and Wildon Fickett. *Detonation: Theory and Experiment*. New York: Dover
   Publications, 2007.

Kohler, Josef and Rudolf Meyer. *Explosives*. New York, New York: WILEY-VCH, 1993.

Mader, Charles L. *Numerical Modeling of Explosives and Propellants, Second Edition*. Boca
   Raton: CRC, 1997.

National Research Council. *Black and Smokeless Powders: Technologies for Finding Bombs
   and the Bomb Makers*. Washington, D.C.: National Academies Press, 1998.

National Research Council. *Containing the Threat from Illegal Bombings*. Washington, D.C.:
   National Academies Press, 1998.

Naoum, Phokion. *Nitroglycerine and Nitroglycerine Explosives*. Baltimore: Williams and
   Wilkins Company, 1928.

Encyclopaedia of Explosives and Related Items. Picatinny Arsenal, NJ: U.S. Army Research
   and Development Command, 0.

The Manufacture of Smokeless Powder
http://www.fbi.gov/hq/lab/fsc/backissu/april2002/mccord.htm